

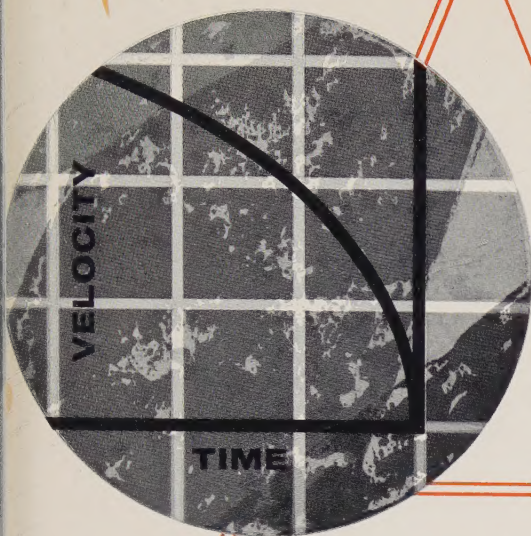
GENERAL MOTORS

Volume 8 - - - - Number 3

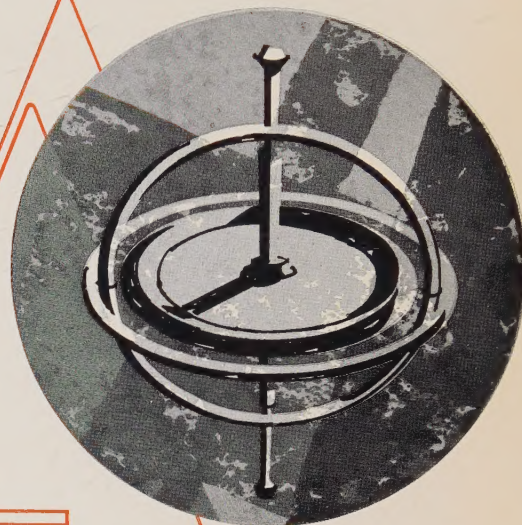
July-August-September, 1963

ENGINEERING JOURNAL

for educators
in the fields of engineering
and allied sciences



acceleration



attitude

THE THREE A's OF INERTIAL NAVIGATION



accumulation

A Statement on Engineering and Education

"ENGINEERING AND EDUCATION"

"Engineering is a profession. Its members do creative work which results in things that people need or want. These things may be highways, submarines, interplanetary vehicles, antibiotics, or television. Science, on the other hand, is a search for knowledge. The science of mathematics extends abstract knowledge. The science of physics extends organized knowledge of the physical world. In each of these, consideration can be limited to a carefully isolated aspect of reality.

"The engineer must deal with reality in all its aspects. He must not only be competent to use the most classical and the most modern parts of science, but he must be able to devise and make a product which will be used by people. Moreover, he must assume professional responsibility insofar as the safety and well-being of people are affected by the thing he makes.

"A sound program which majors in engineering or one of its branches—civil, mechanical, chemical, etc.—will be the most stimulating and rewarding undergraduate experience for the great majority of candidates for engineering. They will find in it not only the science of the modern physicist, but also the other kinds of science—for example, fluid mechanics, or electric-circuit theory—which the engineer uses and develops as incisive means for resolving the complex problems of

the real world. Such a program grows out of an educational environment created by men in contact with the world of people and industry which serves the people. It will include attention to the furtherance of many parts of science which are of special interest to the engineer.

"Engineering education is being urgently called upon to produce graduates well versed in rapidly advancing science who will lead industry and the public into the new world which engineering will make possible. Engineers will often discover in science through their own research and invention or through the findings of scientists those things which can be put to human use. In any engineering achievement, however, the thing produced is the objective, and all means available to the intellect of man will be employed to reach that objective. Science and its application remain a part, but only a part, of any great engineering advance. Supersonic aircraft could have been devised and made only by engineers with great resources in science. In order to make the first supersonic airplane, however, science had to be combined with the engineer's drive toward creation of a predetermined object. Young people who can respond to this kind of challenge are needed now, but they will be needed as never before in the years ahead."

C. S. Draper
J. H. Keenan

T. K. Sherwood
J. B. Wilbur



SOME of today's popular conceptions about engineering and science are misleading and inaccurate. As a result, the distinguishing features of the two fields are only vaguely understood.

This suggests that engineers and scientists could do a better job of informing the public about their respective professions. One segment of the public in particular—high school students and their counselors—needs to have a clear picture of engineering and science. Misconceptions, and sometimes glamour, can lead a student toward a career in one of these fields when the other actually offers him more personal satisfaction and a greater future.

An example of the kind of information that contributes to a better understanding is the accompanying statement on "Engineering and Education." This was prepared recently by a committee of the School of Engineering at the Massachusetts Institute of Technology. Background information about the authors of the statement is presented on page 56.

*C. A. Chayne**
Vice President in Charge
of Engineering Staff

*Mr. Chayne is an alumni term member of the Corporation, Massachusetts Institute of Technology.

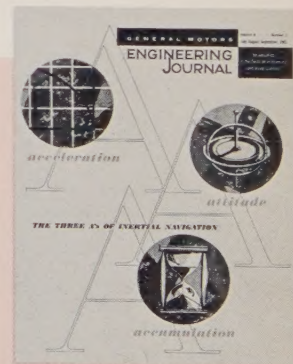
THE COVER

This issue's cover design, by artist Andrew Henkel of AC Spark Plug Division's Milwaukee Operations, uses symbols and the words *attitude*, *acceleration*, and *accumulation* to describe the basic tasks performed by an inertial guidance system.

The gyroscope represents the attitude task of providing a known, stable reference. Three gyroscopes establish a three-dimensional inertial space reference which will not deviate in angular orientation regardless of its location or environment. The acceleration task, represented by the velocity versus time plot, is accomplished by instruments which measure accelerations of the vehicle carrying the guidance

system. These measurements are made with respect to the inertially stabilized directional reference established by the gyroscopes. The hourglass represents accumulation, a term used to denote time-based computation. The use of a chronometer, plus accumulated attitude and acceleration data, allow the computation and issuance of steering commands which position the vehicle on the correct course.

The back cover shows photographs of an inertial measurement unit (upper) and a computer assembly (lower) used in an inertial guidance system produced by AC Spark Plug Division.



CONTENTS

PAPERS IN THIS ISSUE

Page

The Physiological Aspects of Automotive Heating, Ventilating, and Air Conditioning, by <i>William H. Jackson, Harrison Radiator Division</i>	2
Applying Radioisotope Techniques to Engine Wear Measurements, by <i>James J. Gumbleton, General Motors Engineering Staff</i>	7
Automatic Paging System Simplifies Communication Between Two Separated Plants	13
Static Controls for Machines: Evolution and Design of the Transistor Circuits, by <i>Douglas G. Wilson, Delco Radio Division</i>	14
Static Controls for Machines: Application to a Hypothetical Production Machine, by <i>Howard E. Wright, Delco Radio Division</i>	22
How Roadside Ditches and Slopes Can Be Designed for Safety, by <i>Kenneth A. Stonex, General Motors Proving Grounds</i>	31
Some Rules for Determining Inventorship, by <i>Hugh L. Fisher, Patent Section, Detroit Office</i>	37

CLASSROOM PROBLEMS

Solution to the Previous Problem: Develop a Process Plan to Control Tolerance Stack Conditions for a Machined Part, by <i>Robert Dinda and L. C. Lander, Jr., General Motors Institute</i>	48
A Typical Problem in Mathematics: Define the Geometry of the Inner and Outer Tooth Contours of a Gear Type Oil Pump, by <i>Carl M. Schell, Frigidaire Division, Assisted by Gerhard W. Sood, General Motors Institute</i>	53

OTHER FEATURES

Notes About Inventions and Inventors, <i>Contributed by Patent Section, Detroit Office</i>	38
Technical Presentations by GM Engineers and Scientists	44
Contributors to the July-August-September 1961 issue of GENERAL MOTORS ENGINEERING JOURNAL	54

GENERAL MOTORS ENGINEERING

JOURNAL

Vol. 8 July-Aug.-Sept. 1961 No. 3

*Published with the help of
General Motors engineers
and scientists everywhere*

THE GENERAL MOTORS ENGINEERING JOURNAL is published quarterly by the Educational Relations Section of the Public Relations Staff, General Motors Corporation. It is intended primarily as a medium for presenting to educators in the fields of engineering and allied sciences the results of General Motors research and engineering developments in both the product and production fields.

ADVISORY BOARD

L. C. GOAD, Executive Vice President
C. R. OSBORN, Executive Vice President
S. E. SKINNER, Executive Vice President
N. C. DEZENDORF, Vice President
and Group Executive
J. E. GOODMAN, Vice President
and Group Executive
C. A. CHAYNE, Vice President
in Charge of Engineering Staff
A. G. DE LORENZO, Vice President
in Charge of Public Relations Staff
L. R. HAFSTAD, Vice President
in Charge of Research Laboratories
P. J. MONAGHAN, Vice President
in Charge of Manufacturing Staff
Secretary: K. A. MEADE, Manager,
Educational Relations

STAFF

JOHN BRYANT, Editor
THOMAS F. MACAN, Associate Editor
RONALD O. WOODS, Assistant Editor

Public Relations Staff Assistance
Art: ERNEST W. SCANES, Director
JOHN B. TABB, Asst. Director
Production: DONALD O. BRYSON
Distribution: LOUIS W. NORMAN

Address: EDUCATIONAL RELATIONS SECTION, Public Relations Staff, General Motors Corporation, General Motors Technical Center, Warren, Michigan.

© 1961 by General Motors Corporation. All rights reserved under the International and Pan-American Copyright Conventions. Requests for permission to reproduce any part or parts of this publication may be directed to Joseph Karshner.

The Physiological Aspects of Automotive Heating, Ventilating, and Air Conditioning

A challenging engineering assignment is that of designing an automotive heating, ventilating, or air conditioning system. Providing comfort conditions inside the passenger compartment during the winter and summer months presents a design situation totally different from that encountered in the design of such systems for commercial or residential application. Along with the consideration which must be given to basic fundamentals of heat transfer, the engineer also must consider the physiological factors which affect human comfort inside the passenger compartment. These factors have a decided effect on the temperature, velocity, and volume of the conditioned air entering the compartment and also on the manner in which this air is distributed.

THE passenger compartment of today's standard size automobile comprises approximately 150 cu ft of space. During the winter and summer months, this space must be heated and cooled to a satisfactory degree to provide comfortable conditions for driving.

The problems associated with the design of an automotive heating, ventilating, or air conditioning (refrigeration) system to provide comfort conditions inside a passenger compartment are different from those associated with the design of such systems for commercial or residential application. The components of the automotive system are housed inside the engine compartment. Space and weight limitations, therefore, require the components to be as compact as possible. Yet, the components must have sufficient capacity to meet the heating, ventilating, or cooling requirements. Also, the system components must be unaffected by vibration and must be accessible for inspection and servicing.

Besides these requirements relating to component design, the engineer must consider the physiological principles involved when heating, ventilating, or cooling an automobile passenger compartment.

Through the years, experimentation and experience have provided the engineer with basic information pertaining to the physiological principles affecting comfort conditions inside the passenger compartment. The discussion to follow presents some of these physiological principles. However, it is worthwhile to discuss first the human body as a heat transfer device since, in the final analysis,

it is the human body around which the engineer designs his system to provide the required degree of comfort during winter and summer driving.

Human Body a Complex Heat Transfer Device

The average person produces about 10,000 Btu per day of heat energy which is given off to the surrounding atmosphere. The heat is created internally by the slow combustion of food, by the energy expended to maintain life processes, and by muscular activities. The body loses the heat energy it produces by radiation, by convection, and by evaporation.

A basic formula which describes body equilibrium is

$$M - E \pm C \pm R = 0$$

where

M = metabolism (heat produced within the body)

E = evaporation

C = convection

R = radiation.

This formula states that metabolism is always positive (heat energy is always being created within the body) while evaporation, both from the skin and from respiration, is negative. Also, convection and radiation can either take away or add heat to the body, depending on the surrounding physical atmospheric conditions.

Studies conducted by many individuals and organizations during the last 100 years have established that the human body loses heat in the following manner:

- 44 per cent of body heat is lost by radiation to colder surfaces

- 32 per cent of body heat is lost by convection to the air from the skin and mucous surfaces of the nose and throat
- 21 per cent of body heat is lost by evaporation from the skin and mucous surfaces
- 3 per cent of body heat is lost in warming food and for the digestion process.

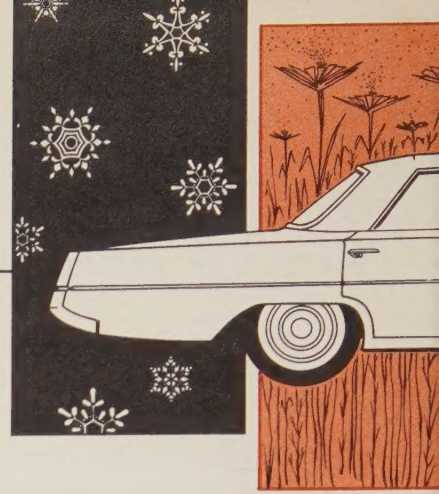
This summary of heat loss points out the importance placed on the temperature of the skin and its ability to dissipate heat to the surrounding atmosphere.

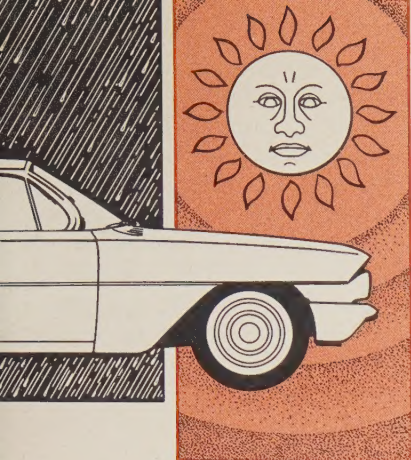
Heat Transferred from Skin Varies with Temperature

The objective of the human body is to maintain, within two to four degrees, a normal deep body temperature of approximately 100°F. When the skin is exposed to a cold atmosphere, heat transfer from the skin is greatly reduced because blood vessels near the surface constrict. This constriction tends to lower skin temperature and, in turn, the amount of heat transferred to the surrounding atmosphere. The restriction of blood flow to the skin surfaces, however, makes a better insulator out of the skin and fatty tissue near the skin surface.

When the skin is exposed to a hot atmosphere, the blood vessels near the surface dilate. This allows from 50 to 60 per cent of the total blood supply to circulate near the skin surface. The skin temperature is warmed and its ability to transfer heat to the surrounding atmosphere is increased.

A thermally comfortable individual may have skin temperatures of 80°F at his toes, 90°F at his upper legs and arms, 95°F at his forehead, and a deep body temperature of approximately 100°F.





By WILLIAM H. JACKSON
Harrison Radiator
Division

What engineers consider
when designing for
human comfort

The control of blood supply either to or away from the skin surface has been copied in principle by the automotive engine thermostat. During cold weather operation, the thermostat limits the flow of engine coolant through the radiator. During hot weather operation, the thermostat allows a full flow of engine coolant.

Perspiration Temperatures Different for Men and Women

During cold exposure, heat transfer from the body may be further reduced by the addition of more clothing. Also, heat produced in the body may be increased slightly by the intake of more food.

Once skin temperatures have risen to 95°F during hot exposure, the entire body surface temperature tends to stabilize at 95°F in spite of increased ambient temperatures. It is at this temperature that sweat glands open and pour fluid onto the surface of the skin. Because of the evaporative cooling effect which then occurs, the 95° skin temperature is maintained or slightly reduced. The 99° to 100°F deep body temperature also is maintained.

The physiological mechanism controlling perspiration and the evaporative cooling effect is seasonal. During summer, perspiration starts at temperatures several degrees lower than in winter. Skin temperatures are influenced by the amount of clothing worn during the summer and winter seasons. Normally, men start to perspire at ambient temperatures which are 4° to 5°F lower than women. The area of thermal stability at which no perspiration occurs is approximately 4½°F wide for men and 10½°F wide for women. This is accounted for, in part, by the tissue below the skin of women. These tissues are equal to approximately four millimeters of fat. As a result, greater

insulation is produced such that the heat loss of women during cold exposure is 10 per cent less than for men. During hot exposure, on the other hand, skin temperatures of women are 1° or 2°F warmer than men. At ambient temperatures above 80°F the metabolic rate of women falls from 15 to 20 per cent below that of men.

Skin Temperature Indicates Degree of Comfort

The many individuals and organizations who have done considerable research work in the heat transfer area agree that skin temperatures correlate quite accurately with comfort. Good skin temperatures have been described as from 90° to 94°F.

If conditions within the passenger compartment of an automobile can be maintained such that the thermal environment is neutral with regard to skin temperatures, the passengers then will be completely comfortable. This is because there will be no blood circulation changes requiring constriction or dilation. There will be no fatigue and distraction caused by the body having to make adjustments necessary to live in an undesirable atmosphere.

An arbitrary index, known as *effective temperature*, has been established and is used in the design of commercial heating, ventilating, and air conditioning systems. This index combines into a single value the effect that temperature, humidity, and air movement have on the degree of warmth or cold felt by the human body in a fairly large room having wall temperatures nearly the same as air temperatures. Effective temperature, however, is a poor yardstick to measure comfort inside the automobile passenger compartment. The principal reasons for

this are that the compartment is more compact and it has a wide expanse of glass which is cold in winter and hot in summer.

Many Factors Affect Human Heat Transfer Inside Passenger Compartment

Thousands of hours of wind tunnel and road tests have helped to establish design patterns for heating, ventilating, and cooling the automobile passenger compartment to provide comfort conditions over a wide range of ambient temperatures. The important factors which affect human heat transfer inside the compartment are conditioned air temperature, air velocity, air volume, humidity, and air distribution.

Conditioned Air Temperature

The desirable outlet temperature range of the heater when a car is operated in ambient temperatures ranging from 0° to 70°F is from 160° to 70°F. The maximum heat requirement is approximately 25,000 Btu per hour. This output provides adequate heat under severe ambient temperature conditions and also provides rapid warm-up of internal passenger compartment surfaces.

The ventilation system provided on all cars manufactured in this country reduces discomfort during summer driving. The system minimizes human body heat loss during ambient temperature conditions ranging from 60° to 100° F.

The desirable discharge temperatures of an automobile refrigeration system range from 40° to 70°F when the car is operated in ambient temperatures ranging from 100° to 70°F. The maximum cooling requirement is approximately 22,000 Btu per hour under severe temperature, humidity, and solar load conditions.

Air Velocity

The velocity of air entering the passenger compartment has a direct effect on the evaporative heat loss from the human body. During cold weather operation, the velocity of the air discharged from the heater must be sufficient to deliver warm air to the rear seat area. However, the velocity must be held to a minimum to prevent an evaporative cooling effect.

The comfort to be provided by ventilation air depends entirely on evaporative heat loss from the passengers. This is achieved by direct impingement of air on

the passengers at velocities ranging from 50 to 1,100 fpm.

The velocity of refrigerated air entering the passenger compartment should be approximately 1,500 fpm. This is sufficient to provide the evaporative cooling necessary to counteract the human body heat gain, due to radiation from the sun and internal compartment surfaces, and to distribute the air within the compartment.

Air Volume

The volume of air delivered to the 150-cu ft passenger compartment either heats or cools the internal surfaces of the compartment, as desired, to minimize radiation heat loss or gain from the human body. The air volume also determines the rate of air change in the compartment. Optimum air volumes for heating, ventilating, and air conditioning are 150 cfm, 500 cfm, and 250 cfm, respectively.

Humidity

The relative humidity of the ambient

air has varying degrees of importance when considering cold and hot weather operation of a passenger car. During heater operation, high humidities do not present a problem. Heating the air reduces the relative humidity to a satisfactory level within the passenger compartment. This is especially true in some southeastern states that experience near freezing temperatures with very high humidities. Counter to this condition is the typical northern winter with low humidities. Humidification of heated air would be advantageous in the northern climate. The water and steam spray methods used in large central heating systems, however, would not be practical for automobile application.

Humidity plays an important role in ventilation. The cooling effect provided by ventilation air is primarily due to evaporation from the human body. This evaporation effect depends on air velocity, air volume, and the relative humidity or ability of the ventilation air to evaporate moisture from the human body.

The humidity present during the oper-

ation of an automotive air conditioner adds a load to the refrigeration system. Since the cooling unit operates below the dewpoint of the entering air, a maximum amount of condensate is removed from the incoming air. Depending on the efficiency of the evaporator surface, the air discharged into the passenger compartment will vary from 90 to 95 per cent relative humidity. This air mixes with the warmer air present in the compartment to provide a resultant 55 to 65 per cent relative humidity. This resultant air mass in the compartment, which is nominally at a dry bulb temperature of 75° F and a relative humidity of 60 per cent, has a good potential evaporative cooling capacity.

Air Distribution

If the correct volume of air at the right velocity and with the appropriate wet and dry bulb temperatures is directed properly into the passenger compartment, excellent comfort conditions are obtained. If the air distribution system is not thoroughly engineered to meet human requirements, however, much of the effectiveness of the conditioned air is lost.

During winter operation when ambient temperatures range from 0° to 70° F, heater air should be discharged at or near the floor level (Fig. 1a). Because warm air rises, this provides good hot air distribution throughout the car. A low level heater discharge also provides warm air around the least clothed, lower skin temperature portions of the body—the legs and feet. The result is a psychological warming effect during the early stages of cold car operation. Heater air should not be projected toward the face since discomfort from a drying of the mucous membranes in the nose and throat will occur. Also, a concentration of hot air on small areas of the body will cause discomfort during sustained driving.

The ideal distribution of ventilation air into a passenger compartment is to flow air over the occupants in an upward direction from the feet. (Fig. 1b). Air having the highest velocity should be directed at the feet and lap, air having a lesser velocity should be directed at the chest level, and air having the lowest velocity should be directed toward the face. Most passenger cars approach this ideal to some extent. Ventilation air is brought into the compartment below

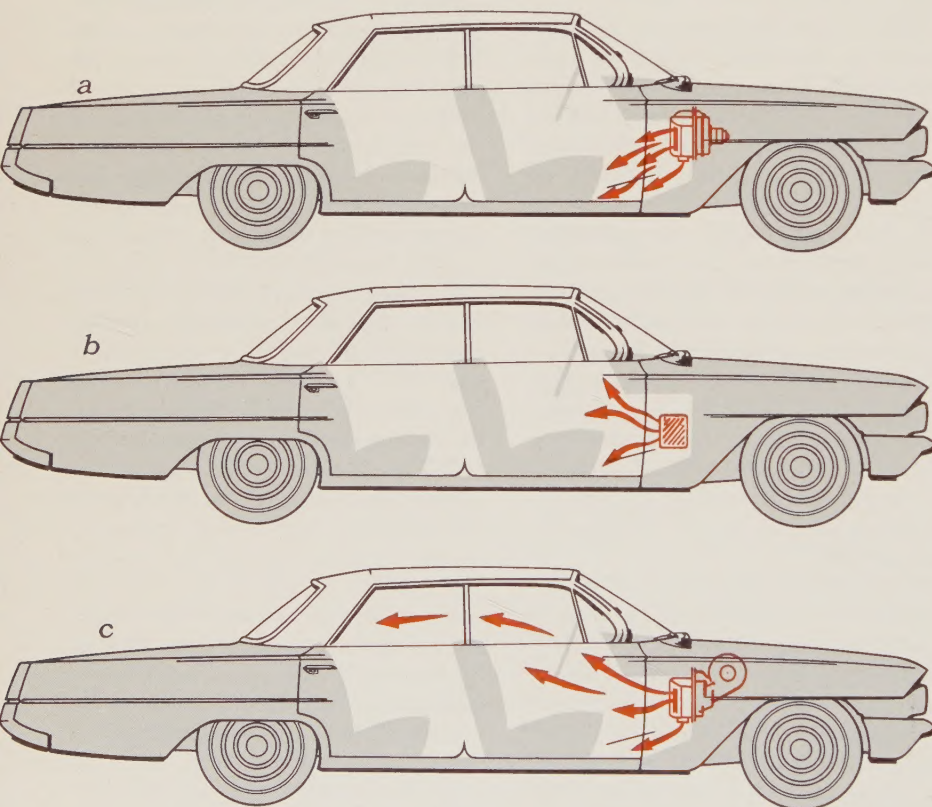
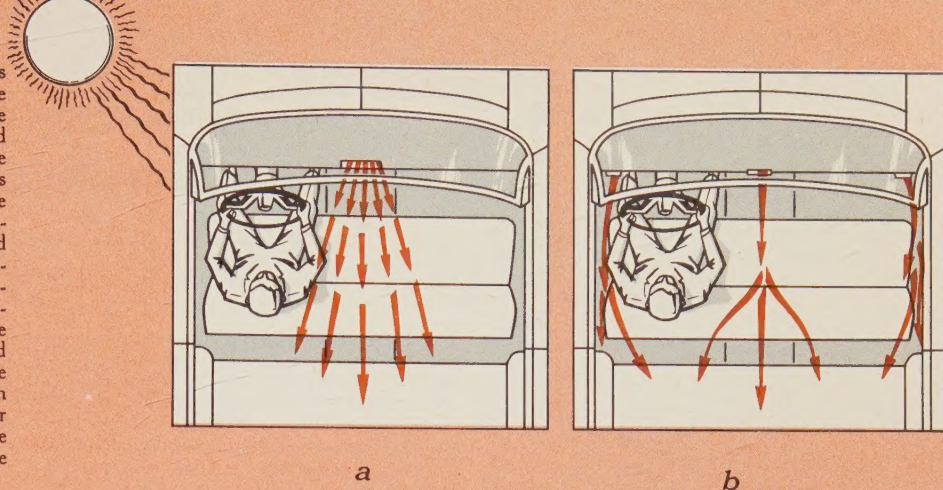


Fig. 1—An automotive air distribution system used for either heating, ventilating, or cooling must be engineered properly to provide maximum comfort conditions. Warm air from the heater (a) should be discharged at or near the floor level to provide good distribution throughout the car as the warm air rises. Ventilation air (b) should be distributed from a point below the instrument panel, then exhausted through the controlled ventilators and windows at shoulder level. Refrigerated air (c) should be distributed to provide cool air to the lap, face, and chest when the system is first started during hot weather and in a parked car situation.

Fig. 2.—These diagrams at the right illustrate two ways in which refrigerated air may be distributed into the passenger compartment. In diagram (a), the air discharge nozzles are arranged so that refrigerated air is distributed only to the inboard side of the driver. The outboard side remains overheated because of solar radiation. This method for distributing refrigerated air is undesirable because the body cannot correct for the unbalanced condition which exists. The skin temperatures on the inboard side of the driver call for less blood flow while the outboard skin temperatures call for more blood flow. Diagram (b) illustrates the preferred way to distribute refrigerated air. The discharge nozzles are arranged to provide an air flow which will cool both the inboard and outboard sides of the driver. Experience gained through extensive road testing has shown that heat added to the human body by direct solar radiation can be offset by an air distribution system which will distribute air to the affected parts of the body in such a way as to increase the evaporative cooling effect.



the instrument panel, then is exhausted through the controlled ventilators and windows at shoulder level. This air flow arrangement provides maximum cooling for those parts of the body which are more comfortable with lower skin temperatures.

The distribution of refrigerated air requires considerable flexibility to meet comfort requirements (Fig. 1c). This system must be capable of discharging cooled air to the lap, chest, and face of the passengers during the early stages of operation in hot weather from a parked car situation. As heat is lost from the body, and the interior surfaces of the compartment cool down, it is essential that the air discharge nozzles be adjustable so that the high velocity air can be diverted from the body to continue to cool the compartment without overcooling local skin areas. A relatively small quantity of air should be delivered to the front floor of the car to provide foot cooling and to counteract radiation of heat from the dash, toe pan, and floor pan. The discharge nozzles should be arranged to cool both the inboard and outboard sides of the passengers (Fig. 2).

Outside Air

Another consideration which must be given to the heating, ventilating, and cooling of an automotive passenger compartment is the control of air quality. The odor level inside the passenger compartment is increased by smoking, by moisture loss from the body because of evaporation, and by the moisture and odors ejected from the respiratory system.

The use of outside air for all heating and ventilating provides a rapid change of passenger compartment air which dilutes the odor level. The side window ventilators are very effective in removing

smoke and odor-laden air without annoying drafts.

The ideal automotive refrigeration system should be capable of operating on 100-per cent outside air during moderate ambient conditions. The system should also have a recirculation feature available for maximum performance under extreme ambient temperatures.

If 100-per cent recirculated air is used, eye smarting will take place when excessive smoking occurs. If 25-per cent outside air is used with 75-per cent recirculated air, however, good air quality within the passenger compartment will be preserved without affecting maximum cooling capacity. The capacity of the refrigeration system should be sufficient to prevent the evaporator temperature from rising above the dewpoint of the incoming air during low speed or idle operation. If the evaporator temperature rises above the dewpoint, the moisture on the evaporator will re-evaporate into the air stream taking with it the odor of materials previously deposited on the evaporator with the condensate.

The use of outside air with the refrigeration system has another advantage. It tends to produce a positive pressure inside the passenger compartment which prevents dust-laden air from entering around the doors and windows. If 100-per cent recirculated air is used, all windows of the car being closed, the air velocity over the shell of the car causes a negative interior pressure which induces air leakage into the passenger compartment.

Paint Color, Glass, Seat Materials Also Affect Comfort

There are other variables, in addition to those just discussed, which affect comfort conditions inside a passenger com-

partment. These include insulation, the color of the automobile body paint, type of glass used, and seat materials.

Insulation

In addition to providing the passenger compartment with a finished appearance, the head lining, door trim panels, and carpeting serve as insulation. Air conditioned cars are provided with additional floor insulation.

Various types of insulation between the roof and head lining have been tested by Harrison Radiator to determine heat transfer characteristics. The results so far have been inconclusive. It can only be summarized that roof insulation offers little advantage based on tests to date. Floor insulation, however, does prove advantageous during heater operation and also permits up to 3°F cooler temperatures inside the passenger compartment during operation of the air conditioner.

Paint Color

Light color or reflective type paint provides certain advantages over darker paints, especially in those parts of the country having hot climates. Tests conducted on white and black colored cars parked in the sun for a one-hour soak period showed that interior temperatures of the white car were 15°F cooler than the black car. Once the cars were in motion, however, roof metal temperatures showed only a 2° to 3°F temperature difference. The benefit provided by the light colored car was in the lower temperatures of the seat, steering wheel, and door trim.

Glass

The large expanse of glass designed into today's automobile has a marked effect on human comfort within the car.

AIR SUPPLY TO EVAPORATOR	POLLEN COUNT ON GLASS SLIDES (GRAINS PER SQ CM)				
	SLIDE ON ROOF OF ENGINEERING BUILDING	SLIDE OUTSIDE THE TWO TEST CARS	SLIDE INSIDE THE NON AIR CONDITIONED CAR	SLIDE INSIDE THE AIR CONDITIONED CAR	SLIDE AT COLD AIR DISCHARGE IN AIR CONDITIONED CAR
100 PER CENT OUTSIDE AIR	49	130	49	0	4.0
80 PER CENT RECIRCULATED AIR	49	41	82	0	3.0

Fig. 3—The effectiveness of an automotive air conditioning system in preventing the entry of air-borne pollen into the passenger compartment was proven by extensive road tests conducted by Harrison Radiator Division. The tests were performed using both air conditioned and non-air conditioned cars. Pollen was collected on glass slides smeared with glycerin jelly. The slides were positioned outside the cars and, for the air conditioned car, were positioned directly in front of the cold air outlet. The table above summarizes the results of the test and indicates the effectiveness of the air conditioning system in preventing the entry of pollen into the passenger compartment during a one hour test period. Shown at the left are reproductions of glass slides showing the pollen collected ahead of the evaporator (a) and at the air outlet (b).

especially during periods of sustained driving.

Air Conditioning System Traps Air-Borne Pollen and Dust

The automotive air conditioning system provides another benefit in addition to that of providing comfortable conditions inside a passenger compartment during hot weather driving. Extensive road and tunnel tests made by Harrison Radiator have proven the ability of the moisture laden evaporator to trap pollen and dust and prevent their entry into the passenger compartment.

Road tests were conducted during the height of the ragweed pollen season using air conditioned and non-air conditioned cars. Glass slides smeared with glycerin jelly were positioned outside the cars and also inside the passenger compartments. The pollen count on the outside slide varied from 35 to 148 grains per sq cm. Under all road test conditions, the pollen count on the slides positioned inside the air conditioned car showed zero pollen count (Fig. 3). The non-air conditioned car had a pollen count up to 82 grains per sq cm inside the passenger compartment. Slides positioned inside the air conditioning outlet collected three to four grains per sq cm of pollen during the one hour test period. The accepted standard for minimum hay fever discomfort is five grains per sq cm.

To substantiate the road tests, controlled tunnel tests were conducted. Many methods for adding pollen to the tunnel air stream were explored as were various methods for measuring the pollen entering the car. The test procedure finally adopted consisted of injecting 200 milligrams (approximately a million

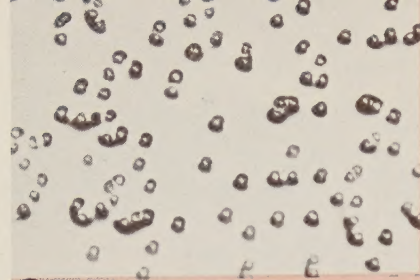
pollen granules) into the cowl air inlet just forward of the windshield. Prepared slides were placed at the air inlet to the evaporator and the air outlet from the evaporator. The slide placed at the inlet to the evaporator was covered with pollen grains too numerous to count. By comparison, the slide on the air outlet side was almost clean. Under the same test conditions, but with the refrigeration system inoperative so that the evaporator core was completely dry, results showed that both the inlet and outlet slides were coated with pollen grains too numerous to count.

The chairman of the Pollen and Mold Committee of the Research Council of the American Academy of Allergy participated in the tunnel tests and concluded that the wet evaporator surface was 98 per cent efficient in removing air-borne pollen.

Conclusions

Human comfort inside the confined automobile passenger compartment varies widely, depending on ambient conditions. The large number of variables affecting comfort, ranging from solar load to seat materials, makes it practically impossible to conclude that all humans will be comfortable if the proper amount of air at the right temperature with reasonable distribution is forced into the compartment.

The problem faced by the engineer when designing an automotive heating, ventilating, or air conditioning system is not one of matching heat transfer requirements to the load imposed on the car. Rather, it is a problem more in the area of providing the system with as much capacity as possible within the limited space available in the vehicle.



During cold weather operation, the cold glass allows radiant heat loss from the face and upper portion of the body. This is a desirable feature after the passenger compartment is warmed. During warm and hot weather operation, the glass allows direct solar radiation on the occupants and also provides large areas of relatively low insulation value. During summer operation, the glass becomes hot and acts as a radiator, adding heat to the occupants.

Clear window glass will transmit approximately 80 per cent of the available heat energy. Most car manufacturers offer tinted and/or shaded glass as an optional accessory. A typical tinted windshield will reduce the transmittance of available heat energy to approximately 24 per cent, which is a measurable improvement to the physiological comfort of the front seat occupants. Based on tunnel and road tests, tinted and/or shaded glass results in as much as 5°F cooler in-car temperatures, in addition to reducing the radiant heat load on the occupants.

Seat Materials

Seat cover materials also affect comfort, especially during summer operation of passenger cars. Non-breathing type seat covers do not allow for evaporative cooling of the back and seat skin surfaces. Excessive perspiration occurs. This is the body's attempt to provide evaporative cooling at the affected areas. The use of breathable type seat covers, however, allows air circulation and will provide evaporative cooling for the back and seat,

Applying Radioisotope Techniques to Engine Wear Measurements

By JAMES J. GUMBLETON
General Motors
Engineering Staff



Wear in a modern internal combustion engine is a slow process; consequently, the measurement of engine wear also has been slow and tedious. The application of radioactive tracers to engine wear measurement appeared to offer a technique which would conserve time and improve test accuracy, while requiring no engine teardown. But, although isotopes can be used to accurately measure wear almost as fast as the wear particles are being removed, the basic nature of wear places practical limitations on their use. The technique, however, can be of assistance in engine wear measurement if it is applied with full consideration of both advantages and limitations.

To evaluate the potential and limitations of the radioactive technique for engine wear measurement, engineers at the General Motors Engineering Staff's engine laboratory applied wear tracer techniques to two different single cylinder engine structures. One engine incorporated a radioactive cast iron top compression ring with an integral cast iron block. The other engine had a radioactive cast iron top compression ring with a radioactive experimental light metal alloy cylinder liner. In general, as radioactive wear debris became entrained in the lubricating oil, it was monitored by a radiation detector producing quantitative wear measurements (Fig. 1).

Iron and Iridium Isotopes Used as Tracers

Upon neutron bombardment, the cast iron piston ring produced the long lived radioisotope iron-59. The experimental light metal liner was alloyed with 0.02 per cent (by weight) of pure iridium to produce the tracer iridium-192. This trace addition of iridium was necessary since the original liner alloy did not contain elements suitable for the production of long lived radioisotopes.

During engine operation, the lubricating oil contained a mixture of radioactive wear debris from both the piston ring and the cylinder liner. Since both iron-59 and iridium-192 are gamma emitters, their

separation was accomplished by electronic instrumentation capable of distinguishing the discrete differences in the energy levels which characterize all isotopes (Fig. 2).

As the piston ring moved relative to the cylinder liner, the wear debris was collected in the lubricating oil and transferred by an external oil pump to a radiation detector (Fig. 3). This detector was a scintillation crystal and produced signals which were proportional to the energy of the emitting gamma radiation. These signals were amplified, and a discriminator in the amplifier transmitted only those signals or gamma rays with energies above a certain level, defined as the *ring wear channel* (Fig. 4). Above the

Limitations and potential
shown by piston ring and
cylinder liner studies

minimum energy of the ring wear channel, the iridium-192 (from the liner wear debris) did not contribute to the total activity. Thus, only the activity resulting from the cast iron piston ring wear was counted on the count rate meter and continuously recorded on the strip chart recorder.

The total signal from the amplifier also was transmitted to the differential analyzer. This analyzer discriminated between gamma ray energies above one given level but below another level, defined as the *liner wear channel* (Fig. 4). This signal was recorded on a scaler-timer unit. The total count in this channel was corrected to yield only the activity caused by liner wear debris by calculating the piston ring debris activity and subtracting it from the total activity (Fig. 4).

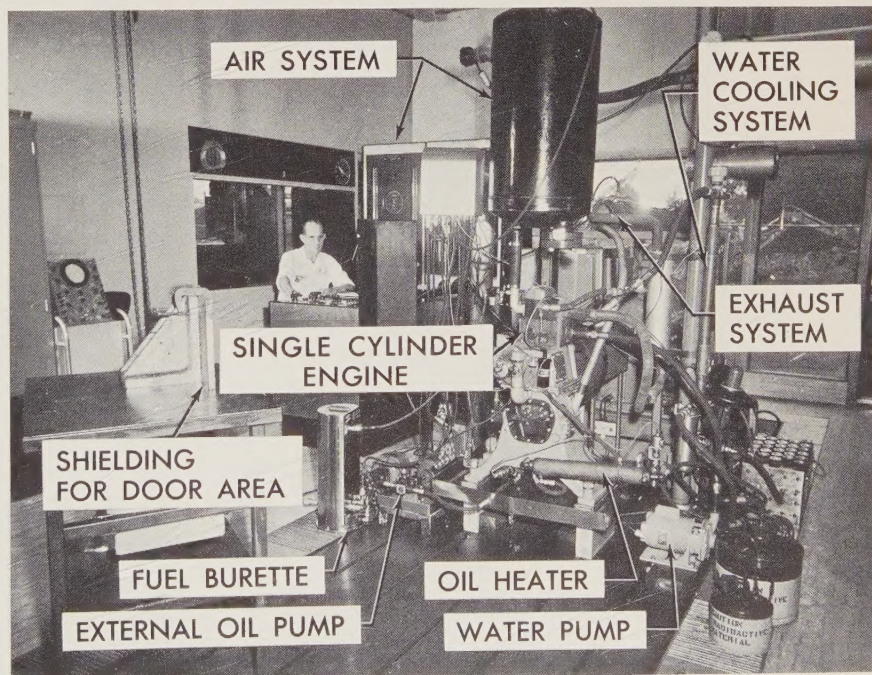


Fig. 1—The single cylinder engines used in the tests were overhead valve designs with wedge type combustion chambers. The wear debris was collected in the engine oil sump and transferred by the external oil pump to the rear of the dynamometer, where the radiation detector was located.

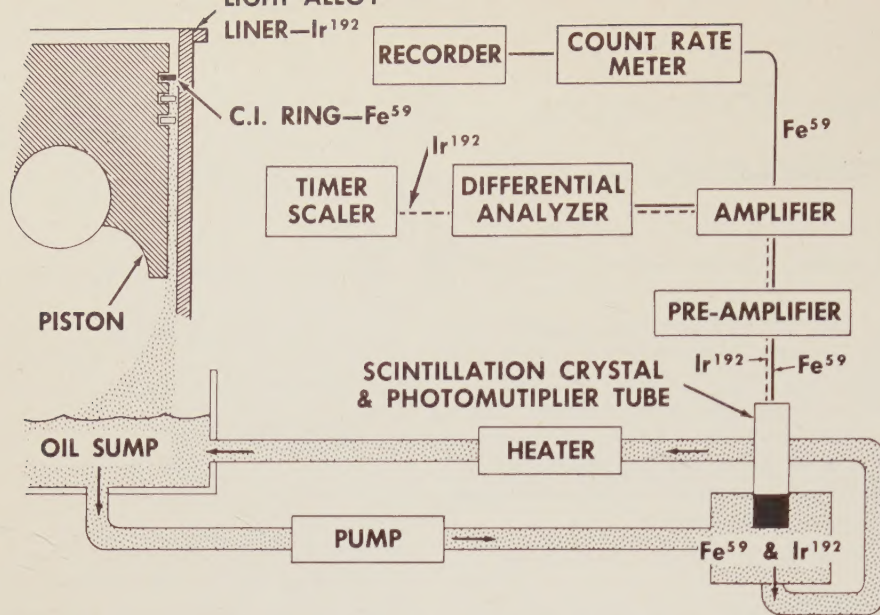


Fig. 2—Since wear debris from both the piston ring (iron-59) and the cylinder liner (iridium-192) were present in the oil sump, electronic instrumentation was necessary to separate the activity of the two isotopes before wear measurements could be obtained.

Wear Data Varied

In early test work, a large variation was noted in repeat data obtained on different days, whereas the repeat data acquired on the same day appeared to be reasonably consistent. The implication of these results appeared to limit the range of answers that could be provided by the radioactive tracer technique. Thus, tests were performed to confirm these results. Repeat wear measurements were made

on the same day with the engine operating at the same speed and load (Fig. 5). This test was repeated on seven different days. The variation observed on any given day appeared random with a trend toward decreasing wear rates with increasing time. This could have been due to more complete conditioning of the bore and ring surfaces on each particular day.

The data were analyzed statistically by first computing the mean value of each

day as well as the mean for the data from all the days. The standard deviation was computed for each mean value. (The standard deviation is a measure of the spread or expected variability about the mean.) For comparative purposes the standard deviation was expressed as a percentage of the mean wear rate value (Fig. 5). Values of standard deviation were expressed as a per cent variation about this mean wear value and were plotted for each of the days on which a set of wear determinations was made (Fig. 6). For the piston ring wear rates the average of these standard deviations was 20 per cent with a minimum value of 9 per cent and a maximum value of 33 per cent.

It is important to bear in mind that these values of standard deviation refer in each case to tests run on the same day. If all data are considered together, irrespective of the day of test, then day-to-day variation in wear rate also is considered in the computation. In this case, considering all piston ring wear determinations as a group, the standard deviation was 56 per cent.

Variations in wear data of this magnitude were not unusual. They merely indicated the random nature of the wear phenomenon. The data showed that relative comparisons of engine parameters made on the same day were reasonably

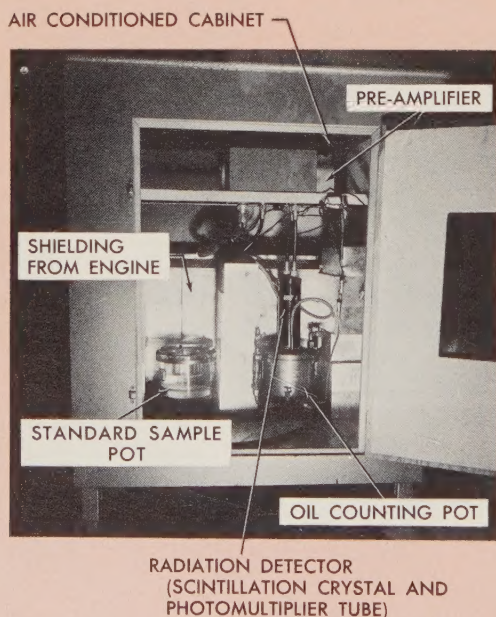


Fig. 3—The radiation detector (left) was inside a well type sample holder, located behind the dynamometer, where the engine oil was monitored. Standard samples with known weights of ring and liner material were used to convert the oil activity into a weight loss in terms of milligrams. The recording instrumentation (right) was located in the control area adjacent to the test cell. The ring wear was recorded continuously on the strip chart recorder. Liner wear was counted on a scaler-timer unit and transferred to the strip chart for the time base.

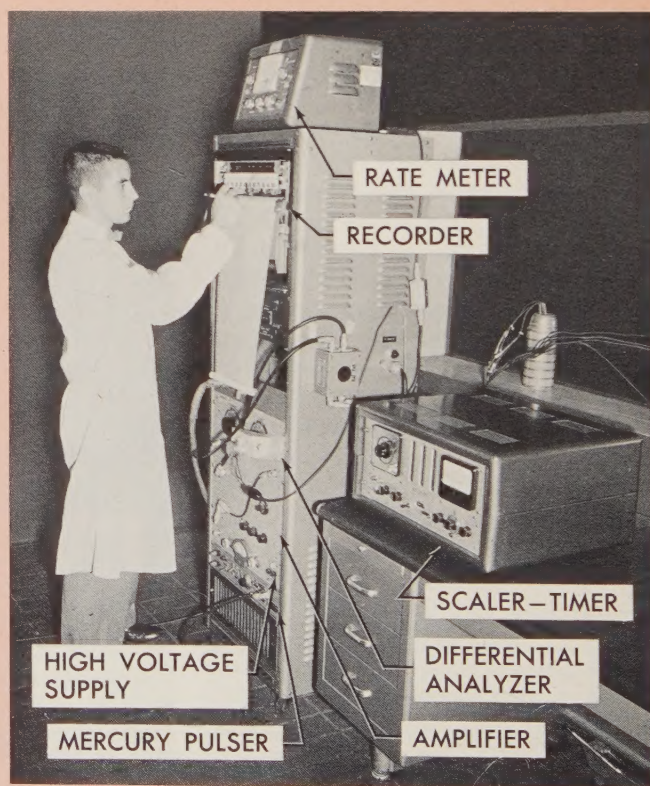
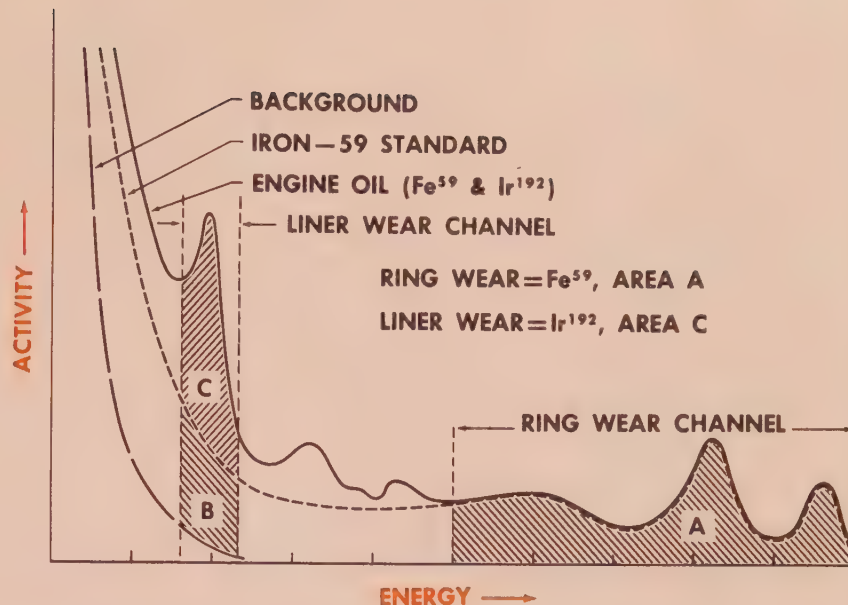


Fig. 4—These energy spectra are differential plots of total isotope activity versus gamma ray energy. The curves were obtained by plotting the activity (counts per minute) which occurred in successive small increments of energy. The spectrum curve for background radiation shows the cosmic radiation which existed in the atmosphere, and which was most predominate at low energies. The energy spectrum for the cast iron piston ring shows the two characteristic gamma ray photopeaks for iron-59, which existed at energy levels of 1.1 and 1.3 Mev (million electron volts). The composite energy spectrum of the lubricating oil, which contained both iron-59 and iridium-192, shows both the iron-59 photopeaks and the characteristic gamma rays for iridium-192, whose principal energy level was at 0.32 Mev.

The amplifier discriminator and the differential analyzer transmitted signals to form, respectively, the *ring wear channel* and the *liner wear channel*. All activity recorded in the ring wear channel resulted from iron-59, and is represented by area A. The iron-59 activity in the liner wear channel is represented by area B. Area C represents iridium-192 activity. By knowing the activity in area A at any given time, the activity of area B can be calculated by a previous definition of the ratio of area A to area B. When the activity of area B is known, it can be subtracted from the total activity in the liner wear channel to give the activity of area C (iridium-192), or liner wear activity.



consistent. Reliable comparisons of engine wear data can be obtained if

- (a) sufficient data points are recorded to insure a good mean value

or

- (b) the spread in the results under the different conditions is sufficiently large that their difference cannot be attributed to the randomness of wear.

From the wide variation in data recorded on different days, relative comparisons between data recorded on different days are very difficult, if not impossible. Extremely large variations in wear under different test conditions would be required to assure that any difference recorded was not due merely to the randomness of wear.

The case for the liner wear rates was somewhat different (Figs. 5, 6). The average of the standard deviations was 23 per cent when tests were run on the same day. This was comparable to that recorded for the ring wear rates, and indicated that the same fundamental causes which produced the variation in wear within a day had similar effects on both the ring and liner wear rates. However, the day-to-day effect, illustrated by the standard deviation of the liner wear data recorded on all the days, showed a deviation from the mean value of only 28 per cent. This was considerably lower than that recorded for the ring wear. This indicated that the under-

lying parameters which produced the large variation in the ring wear rates from day-to-day did not exhibit an equal effect on the liner wear rates. This could have resulted from a number of different causes, such as differences in ring and liner material, geometry, operating functions, and lubrication.

Repeatability of Parameter Influences Tested

To determine the variation in repeat tests of the effect of a single engine parameter, a series of 10 tests was completed on 10 different days in which the effect of engine speed on wear was determined.

The results of these tests showed that both the ring and liner wear rates increased with increasing speed (Fig. 7). An increase in speed from 2,000 rpm to 3,000 rpm approximately doubled both the ring and liner wear rates. However, the differences in wear rates between the ring and liner did not indicate the relative wear resistance of the two materials because there were differences in material density, geometry, and operating function.

These findings illustrated the spread in results to be expected in repeat tests on different days. The top compression ring wear data ranged from a factor of 2.5 at 1,000 rpm to a factor of 2.1 at 3,500 rpm. The liner wear varied by a factor of 4.3 at 1,000 rpm to a factor of 2.5 at 3,500 rpm. This spread in wear data of two to

four times is not uncommon in repeat wear tests. It does illustrate, however, the danger in making comparisons between data run on different days or in different engines.

The individual data points at each speed on a particular day showed some variation from a smooth curve as would be expected from the randomness shown in repeat measurements made at a constant speed. However, reasonable curves could be drawn through the data points and, by noting the consistency in the general slope of these curves, it was concluded that the relative effect of a given engine parameter can be illustrated in a single day.

Caution should be exercised in trying to interpret the mean wear of 10 tests such as these as being indicative of the long term engine life. The engine life cannot be predicted on a short time basis. The wear characteristics of the two surfaces were continually changing, and caution must be used in extrapolating the data. The mean of another series of 10 tests conceivably could be significantly higher or lower than the mean shown in these tests. Thus, for example, to compare different engine materials, a short term test will not indicate their relative resistance to wear throughout the engine life.

Parameter Effects Correlated by Regression Analysis

The data showed a large spread in

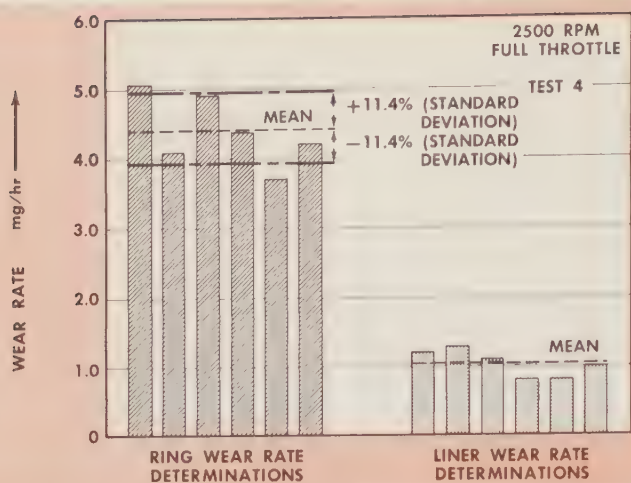


Fig. 5—The normal variation in repeat wear measurements within a single day was obtained by warming up the engine for 45 minutes, then operating it at 2,000 rpm and full throttle. The wear rates were determined during separate 15-minute intervals at this stabilized engine operating condition. The mean wear rate also was plotted with the standard deviation about the mean computed.

repeat test results run on different days while controlling the normal engine parameters. To explain this day-to-day variation in test results, a statistical stepwise regression analysis was used to correlate all the measurable parameters which were not held constant either by test design or by the nature of the parameter.

Regression analysis is useful in studying the interrelationships among a group of variables. If one of the variables is designated as a dependent or response variable, the analysis results in a linear predicting equation using a minimum number of independent or predictor variables. A significant aspect of a stepwise multiple regression analysis is that the relative effect of each variable upon the equation can be evaluated as the equation is constructed step by step. Also, each step in the analysis can provide valuable statistical information. A descriptive treatment of the analysis for the nonstatistician as well as a complete mathematical description of the procedure has been prepared by M. A. Efroymsen¹.

A stepwise regression program was available for the General Motors Research Laboratories digital computer, and was used in analyzing the test data. In this particular application the program was useful in indicating the nature of the variation of the wear results. The ring wear rate was considered as the dependent variable, and the independent var-

iables examined were speed, air-fuel ratio, spark advance, water temperature, oil temperature, intake air temperature, intake air humidity, ambient temperature, ambient humidity, ambient pressure, and shutdown time interval.

The test data were analyzed in two different groups: (a) where the speed varied from 1,000 rpm to 3,500 rpm, and (b) where the speed was held constant. In the group where the speed varied, approximately 80 per cent of the variation in the ring wear could be explained by the change in speed and approximately five per cent of the remaining variations could be explained by a combination of ambient air temperature, humidity, and pressure. The remaining variation could not be explained by the parameters investigated. Since speed was the primary variable in this set of data, it was reasonable to expect the majority of the variation in wear to be attributed to the changes in speed.

When the speed was held constant in the second group of tests, approximately 75 per cent of the variation in the wear rates could be explained by a combination of ambient temperature, humidity, and pressure, and by shutdown interval. The remainder of the variation was not explained in the parameters investigated.

In a regression analysis, caution must be exercised in interpreting the physical significance of the results. The analysis merely indicates general trends in the data and should not be construed to indicate direct cause-effect relationships. The actual cause of the variation in the dependent variable might result from a parameter which was not measured or

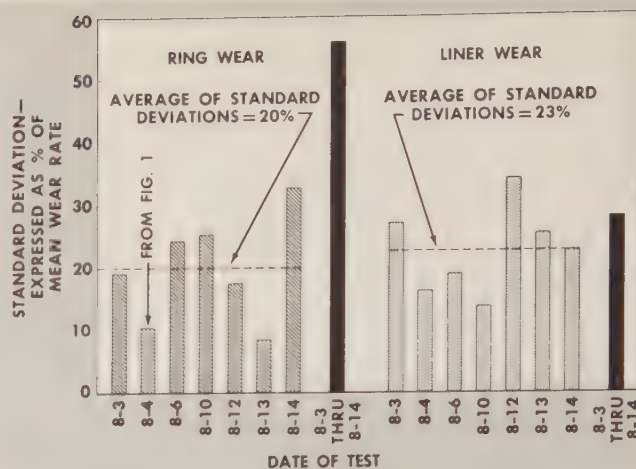


Fig. 6—A statistical analysis of the wear data illustrated the spread or expected variability of repeat measurements recorded on a single day, as well as the variation to be expected when the data are analyzed irrespective of the day of test.

considered in the analysis, but which has a high correlation with one of the independent variables. From the regression analysis, this independent variable might appear to be the principal cause of the effect produced on the dependent variable.

In these engine wear studies, for example, there might have been some parameter which correlated highly with speed, such as the cylinder wall temperature, which might have been the true cause for the variation in wear rate with engine speed. Thus, the parameters which were used to explain the variation in the dependent variable were merely predictors of the effect and conceivably could have been replaced by another set of predictors equally effective in explaining the variation.

The regression analysis of the test data did indicate that the variations in the day-to-day test results were related to the ambient conditions that existed principally during the shutdown period. During the time interval between tests the engine was allowed to cool. This was sufficient time for the occurrence of effects such as corrosion from exhaust products or draining of lubricant from the cylinder walls. These effects or other similar effects could have been related to the ambient conditions and the length of the shutdown interval. When the engine was restarted, a high transient wear period occurred in which a new wear surface was produced. This new surface was not expected to exhibit the same wear characteristics as the previous wear surface and in practice this was demonstrated. However, the

shutdown interval was not necessary to produce this new surface. Continuous engine operation would eventually result in a new surface, but the shutdown interval produced an accelerated change due to the high starting wear.

Effects of Engine Parameters During Normal Operation Evaluated

Since it was shown that the relative effect of a given engine parameter could be illustrated on a single day, the radioactive wear measurement technique was used to evaluate the effect of a number of common engine parameters with respect to piston ring wear. These tests were performed with the single cylinder test engine incorporating a radioactive cast iron piston ring in a cast iron cylinder block. Thus, only the piston ring wear measurements were recorded.

Engine Speed

The cast iron piston ring, in conjunction with the cast iron bore, followed the same general wear characteristics as the cast iron piston ring and light metal bore where the same engine parameters were evaluated in both engines. For example, the effect of engine speed on ring wear, previously shown for the light metal bore (Fig. 7) followed the same general trend of increased wear rates with increasing engine speed.

Engine Load

While maintaining the engine speed at 3,000 rpm, the engine load was increased from 25 per cent full load to 100 per cent full load. This resulted in an increase in piston ring wear by a factor of seven. Since the relative effect of a given engine parameter was consistent, a change in wear of this magnitude was experienced whenever the engine was operated over this load range.

Supercharging

At 2,000 rpm, supercharging the 8.7 to 1.0 compression ratio engine to 12-in. Hg supercharge pressure increased the wear rate from 2 mg per hr at the normally aspirated full throttle condition to 8 mg per hr at 12 in. Hg of supercharge. Therefore, supercharging to this pressure multiplied the wear rate by a factor of four over the unsupercharged full load condition.

Air-Fuel Ratio

At normal operating conditions the

air-fuel ratio had no effect on piston ring wear. While maintaining a constant load by supercharging, the air-fuel ratio was varied from a 9.0-to-1.0 ratio to a 21.0-to-1.0 ratio (the flammability limits of the engine) with no significant change in piston ring wear rate.

Engine Parameter Effects Also Studied Under Abnormal Operation

Engine phenomena such as knock and rumble are considered abnormal engine operation since the engine combustion process is not intended to proceed in this manner. On occasions, however, these conditions do exist. Knock and rumble are associated with objectionable engine noise but generally are not considered to be detrimental to the normal engine life. However, if these phenomena induce preignition, excessive heating of the combustion chamber can result in engine destruction. The effect of these parameters on piston ring wear was investigated.

Knock

The effect of engine knock on piston ring wear rate was illustrated by decreasing the fuel octane quality at a given engine condition. For this test, the engine was operated at normally aspirated full throttle conditions of 2,000 rpm and a 15° spark advance (7° retarded from maximum power).

This test demonstrated that as the knock intensity was increased by lowering the fuel octane quality the wear rate was increased correspondingly (Table I). With the 70 octane fuel, the engine initially was in a medium knock condition and the wear rate was 17.1 mg per hr. As the knock intensity progressed to heavy knock, the wear rate increased until it stabilized at 97.9 mg per hr. Thus, the data clearly showed that abnormal combustion in the form of engine knock produced excessive engine wear.

Rumble

Rumble is a low frequency noise associated with deposit induced multiple ignition. Its pressure-time card is characterized by abnormally high rates of pressure rise and high peak pressures. An accepted opinion in the combustion field is that no cases of engine damage are known to result directly from rumble². Rumble is primarily objectionable because of undesirable engine noise. While engine damage was not observed, tests

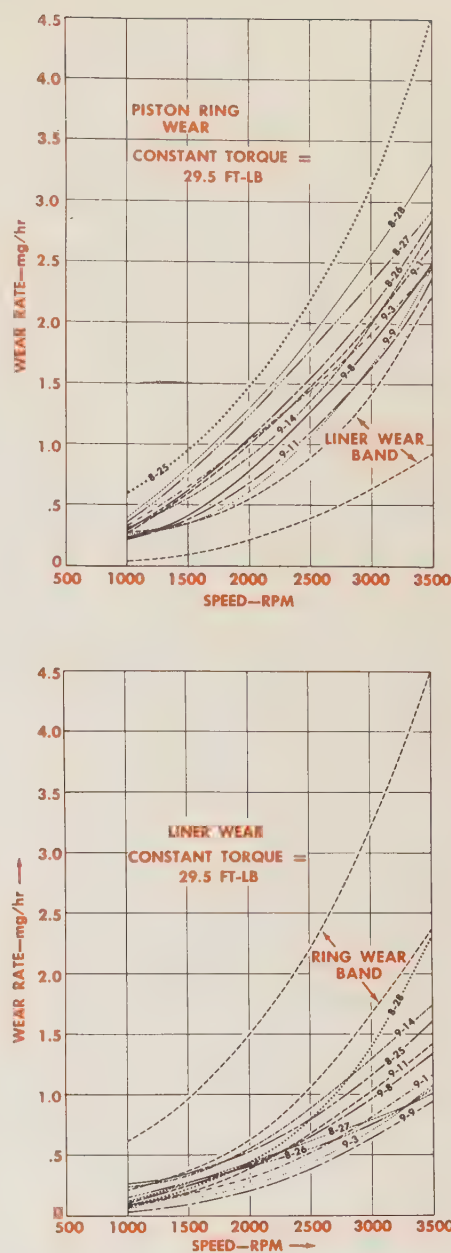


Fig. 7—The consistency of the general slope of these curves illustrates the ability of the radioactive technique to predict the effect of a single engine parameter, whereas the spread in wear data demonstrates the problem in comparing data from different days. After a 45-minute engine warm up period, a 10 to 15-minute stabilized wear rate was recorded at speeds from 1,000 to 3,500 rpm in 500-rpm increments.

with the radioactive ring did show abnormally high wear rates resulting from rumble.

At stabilized engine conditions of 2,000 rpm and full throttle, a wear rate of 0.56 mg per hr was recorded. Ground engine deposits were then inducted into the combustion chamber and the resultant rumble produced an initial wear rate of 36 mg per hr (64 times the normal

wear rate) which subsequently stabilized at a wear rate of 18 mg per hr (32 times the normal wear rate). Strain gage pressure-time cards recorded on a strip film camera during the test confirmed the rumble condition. During rumble the average rate of pressure rise increased from the normal rate of 12 psi per deg to 64 psi per deg, and the peak pressure increased from the normal pressure of 420 psi to 885 psi.

Thus, rumble, as well as knock, was found to be objectionable not only because of noise, but also because of excessive piston ring wear. Although the increase in wear rate for rumble was not as high as for heavy knock, from a practical standpoint it could be more harmful since severe rumble is more likely to be encountered in engine service than severe knock. The increase in wear rate for rumble was considerably higher than for light knock, which is the type of knock most commonly encountered in engine operation.

Summary

The problem of engine wear and its measurement has intrigued experimenters for many years. The recent advent of isotopes was thought to present a rapid and highly sensitive tool for the measurement of wear. The recording of changes in single cylinder engine piston ring wear as small as 12 micrograms illustrated its sensitivity. The speed of isotopes was shown by their ability to record transient engine wear within a two-second time interval. The sensitivity and speed of the isotope tracer technique allowed qualitative measurements to be made comparing the effects of various engine operating parameters^{3, 4, 5}.

Repeat measurements of piston ring and liner wear made on different days showed a variation in test results by a factor of two to four. A stepwise regression analysis indicated that the variation in wear was related to the ambient conditions that existed, principally during the shutdown period. This shutdown period resulted in high starting wear and produced a new wear surface which would very likely exhibit a different wear rate. This continuously changing engine wear surface prevents prediction of long term engine wear on the basis of a short time test.

The random nature of wear has been illustrated by other experimenters in basic wear studies. Rabinowicz⁶ states

that repeat wear tests often differ by factors of two and three, and sometimes as much as ten. Bowden and Tabor⁷ emphasize that any slight change in the operating conditions may change the whole nature of the wear process. Cattaneo and Starkman⁸ measured piston ring wear by weighing the ring, and their results showed variations in repeat measurements by factors of three to five.

Thus, it is evident that comparisons between wear tests from different intervals of the engine life cannot be made readily. Normal wear measurement techniques, which rely on measuring changes in engine wear over a long time

Bibliography

1. EFROYMSON, M. A., "Multiple Regression Analysis," *Mathematical Methods for Digital Computers* (New York: John Wiley and Sons, Inc., 1960), p. 191.
2. FELT, A. E., WARREN, J. A., and HALL, C. A., "Rumble—A Deposit Effect at High Compression Ratios," *S.A.E. Transactions*, Vol. 67, 1959, p. 138.
3. GREEN, F. L. and SOMERVILLE, A., "Continuous Counting of Gamma Rays from Hot Radioactive Liquids," *Nuclear Science and Engineering*, Vol. 7, No. 4 (April 1960), p. 320.

WEAR MEASUREMENT RESULTS		
CONDITION	WEAR RATE (MG PER HR)	WEAR MULTIPLIED BY
NORMAL COMBUSTION 106 Octane Fuel	0.56	1
TRACE KNOCK 80.0 Octane Fuel	1.7	3.0
LIGHT KNOCK 77.5 Octane Fuel 75.0 Octane Fuel	2.5 3.6	4.4 6.4
MEDIUM KNOCK 70.0 Octane Fuel HEAVY KNOCK 70.0 Octane Fuel	17.1 to 97.9	30 to 174

Table I—The results of wear measurements under engine knock conditions showed that wear rates increased as the knock increased. This table also shows the ratio of knock induced wear rate-to-normal wear rate (right column).

period, result in averaging the random variations and are more reliable than trying to predict wear on the basis of a relatively short test. Even in long time period testing, care must be exercised to assure that comparable testing conditions are employed. For example, to determine engine life expectancy, the total number of engine miles for a given test should not be the only criterion of equal testing conditions. The number of engine starts, and the length and number of the shutdown intervals, as well as the ambient weather conditions during the tests will affect the final results.

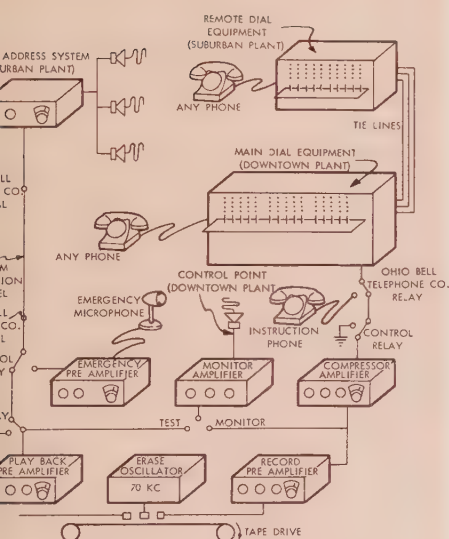
Acknowledgement

The author wishes to acknowledge the appreciable contributions of his colleagues at the General Motors Technical Center, especially in the Power Development Group of the Engineering Staff, and the Physics Department, Fuels and Lubricants Department, Special Problems Department, and the Metallurgical Engineering Department of the Research Laboratories.

4. GUMBLETON, J. J., GREEN, F. L., and MAYER, W. J., "Transient Piston Ring Wear in Automotive Engines Using Fe-59," *Nuclear Science and Engineering*, Vol. 7, No. 4 (April 1960), p. 313.
5. GUMBLETON, J. J., "Piston Ring and Cylinder Wear Measurements Illustrate the Potential and Limitations of the Radioactive Technique," S.A.E. Paper No. 324A, presented at S.A.E. National Automobile Week meeting, Detroit, Michigan, March 15, 1961.
6. RABINOWICZ, E., "New Coefficients Predict Wear of Metal Parts," *Product Engineering*, Vol. 29, No. 25 (June 23, 1958), p. 71.
7. BOWDEN, F. T. and TABOR, D., *The Friction and Lubrication of Solids*, (London: Oxford University Press, 1950), p. 285.
8. CATTANEO, A. G. and STARKMAN, E. S., "Fuels and Lubrication Factors in Piston Ring and Cylinder Wear," *Mechanical Wear*, published by the American Society for Metals (January 1950), p. 47.

Automatic Paging System Simplifies Communication Between Two Separated Plants

DELCO PRODUCTS DIVISION, located in Dayton, Ohio, has two plants—the main plant in downtown Dayton and a suburban plant five miles away. To simplify the handling of paging messages at the suburban plant, a unique automatic paging system recently was put into operation. The new system, developed by Delco's Plant Engineering Department, permits direct paging by telephone. A schematic diagram of the system is shown in the accompanying sketch.



Wherever possible, standard communications equipment was used. All components of the paging system were selected for simplicity of design and operation and are of rugged construction to permit unattended operation up to 1,000 hours. Development of the paging system was under the direction of Donald C. Neubauer, senior electrical engineer.

Paging messages at the suburban plant were formerly handled by a telephone operator. Messages to be relayed when

the operator was not on duty were handled by plant protection personnel. Now, all paging messages are handled automatically.

The paging system is simple in operation. A caller in either the main plant or the suburban plant may use any telephone in the building. A code number is dialed first, then the paging message is made. This message is recorded on magnetic tape. After a 10-second delay, the message is broadcast over a public address system.

Included in the design considerations for the paging system were the transmission level of every telephone within either plant, the transmission level of the five-mile tie lines between the two plants, the proximity of the phones with respect to the loudspeakers (from the standpoint of feedback), and the reliability and continuity of the service.

The primary components of the paging system include an automatic volume control, a monitor-amplifier speaker, a magnetic tape recorder, a compressor amplifier, a preamplifier, and necessary control relay equipment between the telephone dial equipment and the existing paging system.

The most unique component of the paging system is the specially modified magnetic tape recorder which records the message, plays it back through the public address system after a 10-second delay, and then erases the message. Each message is monitored and may be prevented from playback if necessary. This provides a protection against possible unauthorized messages. The recorder is automatically started and stopped for each message or series of messages. This minimizes wear of the tape, pick-up heads, and driving mechanism. Plate voltage for the power amplifier also is supplied automatically to increase tube life and conserve power consumption.

Cooperation between Delco Products engineers and the Ohio Bell Telephone Company produced a paging number and associated standard telephone which serves the following functions:

- (a) When the paging number is dialed, the caller is automatically connected to the system input
- (b) If a paging call is already in process, a second caller receives a busy signal
- (c) When the hand set of the telephone is lifted, playback of the message is prevented and the monitor may talk to the caller.

The paging system also has a microphone and a preamplifier which can be used by plant protection personnel in the headquarters office at the main plant to make any necessary emergency announcements. This microphone has precedence over all other signal sources.

An important part of the paging system is a relay rack which was designed by Delco Products engineers to perform the following functions:

- *When a paging message is initiated—*
Immediately starts tape drive mechanism; applies plate voltage to power amplifier tubes; connects incoming signal to compressor amplifier; connects playback preamplifier to power amplifier
- *When a paging message is interrupted—*
Continues the tape drive motion and erase function; immediately disconnects and shorts input to compressor amplifier and to power amplifier
- *When a paging message is completed—*
Immediately disconnects and shorts compressor amplifier input; stops tape drive mechanism after three minutes; disconnects and shorts power amplifier input after 10 seconds; removes plate voltage to power amplifier after 10 seconds
- *When an emergency message is initiated—*
Applies plate voltage to power amplifier tubes; connects emergency microphone and preamplifier to power amplifier; disconnects all other input sources.

The new paging system has made it possible to consolidate all plant protection headquarters functions in the main Delco Products plant. By eliminating a headquarters office at the suburban plant, a better control of activities has been achieved. In the event of an emergency, all activities can be coordinated from one central point instead of from two separated points.

Evolution and Design of the Transistor Circuits



By DOUGLAS G. WILSON
Delco Radio
Division

A reliable control system for complex machines is now possible through the application of transistors as static switching devices. Known as the *Delco Static Control*, the system is based on applications of Boolean algebra and is achieved because transistorized circuits can perform basic logic functions. The basic logic circuits are simplified further by substituting a circuit representing a multipurpose function, called a NOR function. The physical form of the static control system consists essentially of small circuit boards arranged in groups and mounted in racks for installation on a machine control panel. The system was developed because of a growing need for controls which could reduce, or eliminate, the troublesome maintenance problems with conventional relay-switch circuits. The need is especially significant in the case of those production machines that are more complex and have faster cycle times. Problems of both an electrical and mechanical nature had to be solved by Delco Radio Division engineers in developing the static controls so as to provide flexibility, simplicity, and reliability.

TRANSISTORS, in addition to their widespread applications in radios, computers, and military equipment, also are being used as static switching devices to control complex production machines.

The trend of industry toward more complex process operations and faster information handling procedures has resulted in a need for fast but reliable machine controls. The first commercially accepted static control systems used magnetic amplifiers as both logic elements and power amplifiers. When properly applied, these units gave completely trouble-free operation. High initial cost and maintenance difficulties, however, prevented these static controls from being completely accepted by industry.

The transistor, on the other hand, has established itself as a highly reliable device, and transistor circuits are known to be ideally suited to replace relays. Another favorable feature is that transistorized circuits operate on d-c current, which simplifies some of the problems of the control system designer and the maintenance electrician. Thus, engineers have applied the transistor to static controls to attain the features of faster operating speed, high reliability, and small space requirements.

Using the Basic Logic Functions in a Control System

In static control applications, transistors are used predominately as switches

although they also are used as proportional amplifiers. As switches, transistors accomplish logic, timing, and power amplification functions.

To understand how transistors perform a logic function in a static control system, it first may be helpful to discuss basic logic and conventional relay-switch circuits.

The basic logic functions in relay-switch circuits generally are arranged as:

- Parallel circuits for OR functions
- Series circuits for AND functions
- Inverted circuits for NOT functions
- Latched-up circuits for MEMORY functions (Table I).

The analysis of a machine relay control system often is facilitated by using a mathematical technique known as Boolean algebra. In its present form, Boolean algebra expresses conditions of switch continuity or redundancy by simple functions whose values take the magnitude of *one* (1) if a switch is closed allowing the signal to pass, or *zero* (0) if the switch is open.

For example, the Boolean expression for an OR function is:

$$A + B + C = X$$

where

X = the OR function of three switches A , B , and C (Fig. 1).

Transistorized devices
perform logic functions
with fewer moving parts

The plus sign indicates the Boolean operation for the OR function because of the implied addition of currents in parallel circuits. Actual addition of signal magnitudes has no meaning for situations where more than one signal is 1 since a 1 output is the greatest value that a logic function can possess.

The 3-input AND function is treated in a similar manner. Its Boolean expression is:

$$A \cdot B \cdot C = X.$$

The multiplication dot is used because the series switch circuit has similar properties as the multiplication operation. This means that the substitution of 0 for any input renders the output $X = 0$. Conversely, when switch inputs A , B , and C are each 1 the output X is 1. All possible combinations of input to a logic circuit, and the results, are stated in a *truth table* (Fig. 2).

The only other basic logic function which has a Boolean expression is negation NOT. The truth statement for this function is: if switch A is NOT opened (not actuated), the relay is energized. A truth table would state that the output is 1 when $A = 0$ (switch not actuated) and inversely the output is 0 when $A = 1$ (switch actuated). The Boolean expression is:

$$\bar{A} = X.$$

The bar over the input function A symbolizes inversion. In other words, for $A = 0$, $\bar{A} = X = 1$ and conversely for $A = 1$, $\bar{A} = X = 0$.

This discussion has considered the basic logic functions as having three input signals for the OR and AND functions. In practice, however, the designer of a

machine control system might encounter OR and AND situations having any finite number of inputs. Even if the designer only has use of 3-input logic functions, he still can synthesize the functions without difficulty regardless of the number of inputs. For example, a 12-input OR function can be synthesized by using four, 3-input OR logic functions (Fig. 3—top). The Boolean expression for this function is:

$$X = V + T + U = R + S + T + U$$

$$X = A + B + C + D + E + F + G + H + J + K + L + M.$$

Similarly, a 9-input AND function can be synthesized by using three, 3-input AND functions (Fig. 3—bottom). The Boolean expression for this function is:

$$W = X \cdot Y \cdot Z$$

$$W = A \cdot B \cdot C \cdot D \cdot E \cdot F \cdot G \cdot H \cdot J.$$

Since the Boolean expressions do not involve time, they only can describe instantaneous conditions. The MEMORY function, therefore, requires a feedback process to retain an output state after the signal is removed. This feedback requires a finite time to go through the transition

period which cannot be formulated explicitly by the Boolean algebra. This does not present any difficulty since the AND, OR, and NOT expressions can be used to analyze any combinational or sequential switching device or network (Fig. 4).

A NOR Function Substitutes For Basic Logic Functions

Although the basic logic functions are achieved by straightforward circuit design using transistors, a decided advantage in circuit simplification is gained by using a multipurpose logic function to

RELAY-SWITCH LOGIC CIRCUIT	FUNCTION	LOGIC SYMBOL
	OR	
	AND	
	NOT	
	MEMORY (ON-OFF)	

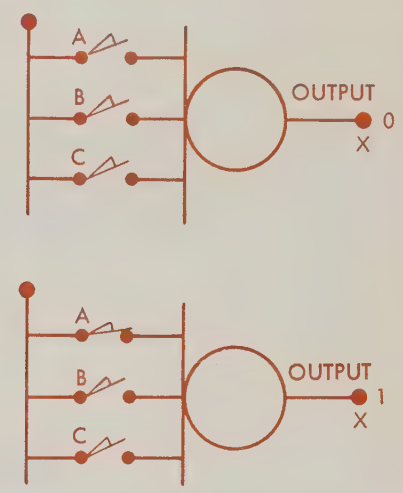


Fig. 1—Applying Boolean algebra to the logic symbol for an OR function (above) shows that when switch A is closed (or switch B or C), a 1 input signal is applied to the OR unit and a 1 output results. A schedule of all possible combinations of switch input signals (below), usually called a *truth table*, shows that an OR function has a 0 output as long as input A, B, and C, are 0. The output is 1 for all other combinations of input signals, even if two or three 1 inputs are applied, since 1 is the greatest value a logic function can possess.

OR FUNCTION TRUTH TABLE	A	B	C	X(OUTPUT)
	0	0	0	0
	1	0	0	1
	0	1	0	1
	0	0	1	1
	1	1	0	1
	1	0	1	1
	0	1	1	1
	1	1	1	1

Table I—The basic logic functions in relay-switch circuits are represented by the circuits and logic symbols shown here.

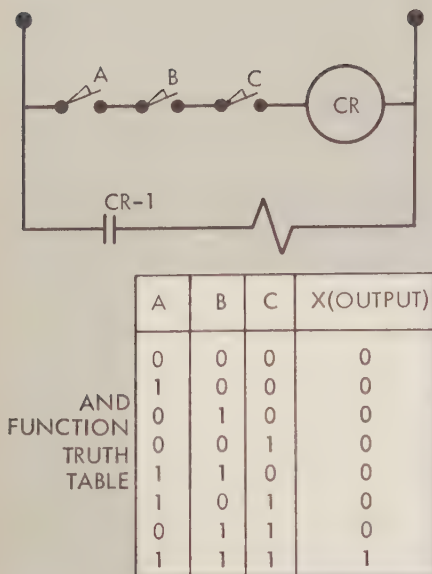


Fig. 2—This truth table for the AND function shows all possible combinations of switch input conditions. It indicates that the only time a 1 output occurs is when each of the three switches is closed.

Fig. 4—The relay-switch logic circuit for the MEMORY function (a), commonly called a self-holding or latching relay, is energized whenever switch A is actuated and switch B is not actuated. This condition must be sustained long enough for the self-holding contacts CR-1 to make up, thus providing a parallel path for signal passage. If switch B subsequently is actuated, the relay is de-energized and returns to its former state. Output functions are controlled by either normally open or normally closed contacts on the relay. Both the ON and OFF sections of the MEMORY's logic symbol (b), provide outputs corresponding to the normally open and normally closed relay contacts.

The truth table at the right for a relay-switch MEMORY function has meaning only for a sequence of switch actuation as given by proceeding from top to bottom. Assume that initially the ON output is 0 and the OFF output is 1 with A and B both 0. A 1 signal at A momentarily makes the ON output go to 1 (turns it on) and makes the OFF output go to 0 (turns it off). By definition, this condition remains after the A input goes to 0 while a momentary 1 input to B returns the outputs to their original condition.

The lower portion of the truth table shows the conditions of the relay-switch MEMORY function when 1-input signals are present simultaneously. In case No. 1, where a 1 signal is continuously applied to input B, a 1 signal is applied to input A. Obviously, actuating switch A after switch B is already actuated has no effect on the output. Conversely, in case No. 2, actuating switch B after switch A is actuated causes the relay to be de-energized and the output reverts to the original state. This behavior is significant since transistor MEMORY devices generally do not behave like relay-switch MEMORY devices with respect to overriding input signals.

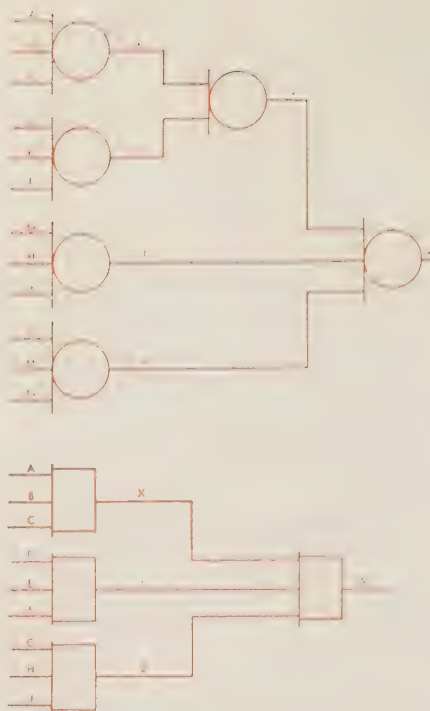


Fig. 3—The top diagram shows a 12-input OR function synthesized by using four, 3-input OR logic functions. The bottom diagram shows a 9-input AND function synthesized by using three, 3-input AND functions.

synthesize the basic logic functions. Such a multipurpose function is the NOR function which can be considered an OR followed by a NOT (Fig. 5). The Boolean expression for the NOR is:

$$Y = \bar{X} = \overline{(A + B + C)}.$$

Using Boolean algebra, it is easy to confirm the equivalence of any given NOR network to the basic logic functions. The simplest use of a NOR function is to perform inversion. This is accomplished by merely using a single input making the element a NOT function. This property of inversion is useful in synthesizing the basic logic functions.

In a network of three NOR functions, each using a single input connected to a fourth NOR function (Fig. 6), the Boolean expression for the fourth NOR is:

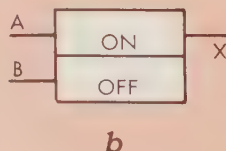
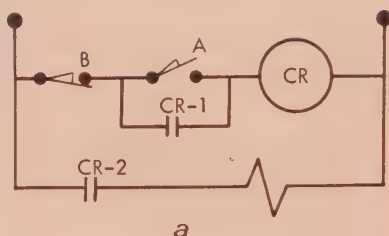
$$\bar{X} = D + E + F$$

or inversely

$$X = \overline{(D + E + F)}.$$

The expressions for the first three NOR functions are:

$$D = \bar{A}, E = \bar{B}, \text{ and } F = \bar{C}.$$



RELAY SWITCH MEMORY FUNCTION TRUTH TABLE

	A	B	ON OUTPUT	OFF OUTPUT
	0	0	0	1
	1	0	1	0
	0	0	1	0
	0	1	0	1
	0	0	0	1
CASE 1	0	1	0	1
	1	1	0	1
CASE 2	1	0	1	0
	1	1	0	1

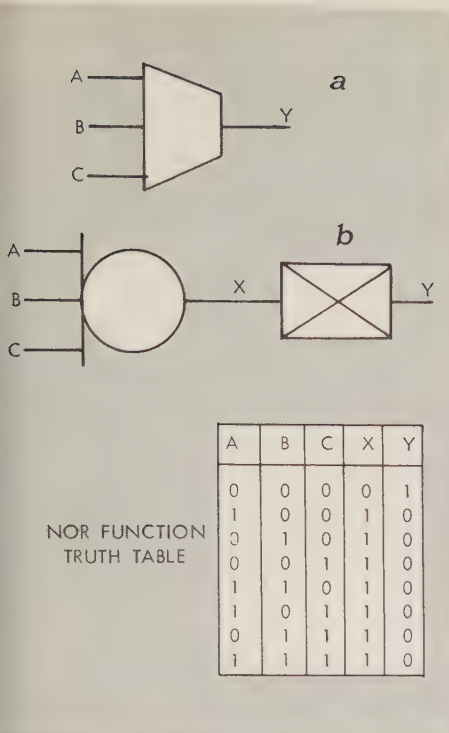


Fig. 5—The logic symbol for the NOR function (a) is simply a combination of the OR function and the NOT function (b). The NOR truth table (c) shows that $Y = 1$ only when switches A, B, and C are 0.

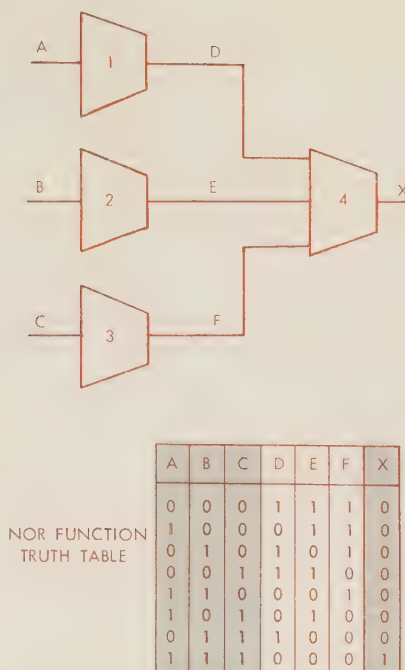


Fig. 6—The diagram at the top shows a network of four NOR functions in which No. 1, 2, and 3 use only a single input while NOR 4 uses three inputs. Columns A, B, C, and X in the NOR truth table are identical to the same columns in the truth table of the AND function (Fig. 2), thus proving the ability of the NOR to perform simple inversion.

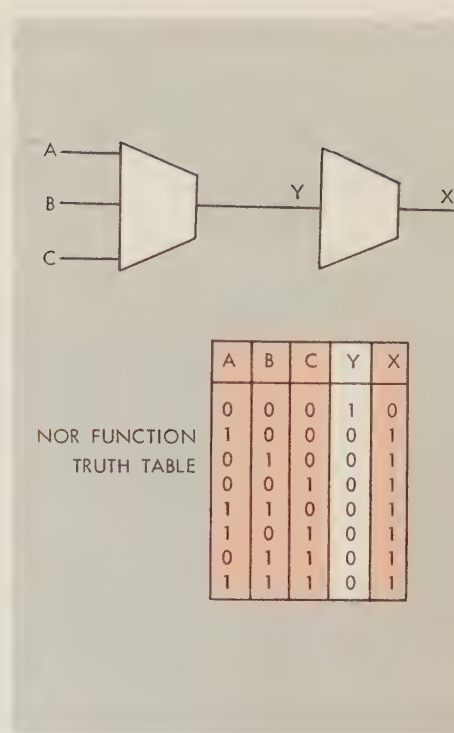


Fig. 7—The diagram at the top shows the NOR function which is equivalent to a 3-input OR. Columns A, B, C, and X in the NOR truth table are identical to the same columns in the OR truth table (Fig. 1), thus proving the ability of a NOR function to describe a 3-input OR.

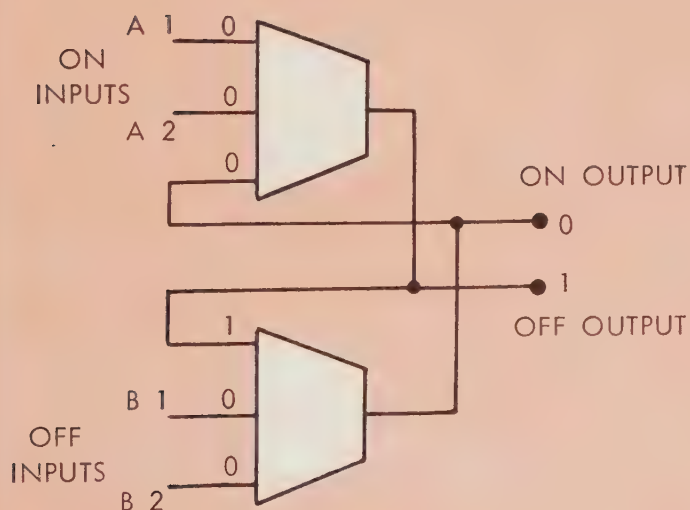


Fig. 8—A MEMORY function is obtained by cross connecting two NOR functions. The outputs from the ON and OFF sections are applied to the opposite inputs of these sections. Each section has two inputs rather than the single input allotted to the symbol for the MEMORY shown in Table I. This results from using 3-input NOR functions in the MEMORY configuration. Each of the input pairs has equal control of the action of the circuit. For example, a steady-state condition in which the A and B inputs are zeros and the ON and OFF outputs are 0 and 1, respectively, satisfies the conditions for the NOR units and agrees with the first line of the MEMORY truth table shown in Fig. 4. If A and B signals are applied to the NOR MEMORY, the truth table shows agreement for all conditions in the top section of the table. For the conditions of the overriding signals, however, both MEMORY outputs go to 0. This is an effect which control system designers must take into consideration when using NOR functions.

Substituting these functions into the preceding expression for X gives

$$X = \overline{(\overline{A} + \overline{B} + \overline{C})}$$

Using DeMorgan's theorem¹ for relating AND to OR functions, the last expression becomes:

$$\overline{(\overline{A} + \overline{B} + \overline{C})} = A \cdot B \cdot C$$

Therefore,

$X = A \cdot B \cdot C$, which is the Boolean expression for the AND function.

The equivalent NOR function for a 3-input OR function is obtained similarly (Fig. 7) while a simple MEMORY function is achieved by cross connecting two NOR functions (Fig. 8).

Development of the System Began with Device Selection, NOR Circuit Design

Fundamentals of the logic functions, as just described, together with the ability of the transistor to perform in logic circuits formed the basis for the development of the Delco Static Control system. Since several types of Delco transistors were available and their performance and reliability characteristics were established, the design task was one of device selection and appropriate circuit arrangement.

The NOR function, as stated, is essentially a 3-input inverter. Since the common emitter transistor amplifier effects signal inversion, the selection of appropriate input coupling networks and operating points is necessary to produce a transistorized NOR circuit. Other important NOR circuit design considerations include:

- Speed of response
- Range of operating temperature
- Level of output power.

It is obvious that any device behaving as a switch will dissipate a minimum of power in either the steady ON or OFF condition as contrasted to a partially transmitting state. Since the Delco junction transistor has a very low power dissipation and temperature rise in either the ON or OFF state, control circuit reliability is improved greatly.

To obtain a multiplicity of input signals coupled to the common emitter configuration, it is simplest for over-all system design to perform all logic by sensing discrete and steady signal levels. For this purpose, direct coupling is

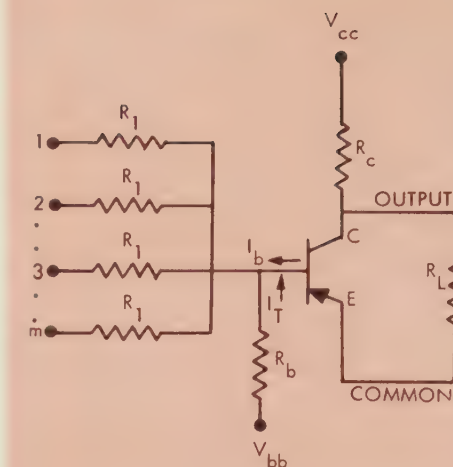


Fig. 9—The base-emitter configuration has the basic requirements of a NOR function device. This circuit shows a finite number of signal inputs m , each coupled to the transistor base through a large resistor R_1 . The selection of the desired number of outputs is somewhat arbitrary. Experience has shown, however, that 3-input logic devices accommodate a majority of machine control requirements.

A 0 signal voltage existing at any of the inputs also represents a logical 0. In addition, the presence of a signal voltage at any one input must be sufficient to cause the NOR output to be 0. The existence of signal voltages at any other input cannot change the output from the logical 0 condition. If the output of the transistorized NOR is taken to the load R_L , then the 0 output condition for a 1 input consideration essentially is fulfilled. For the junction transistor, a saturating input signal reduces the collector to an emitter voltage drop of less than 0.2 volts. This voltage is designated as the logical 0 state. In this condition, the transistor "switch" is conducting but since it shunts the output no signal passes. This is in contrast to the conventional use of switch elements in relay-switch logic.

preferred since the least amount of signal manipulation is required. With this in mind, the common-emitter configuration bears consideration (Fig. 9). This circuit presents a very low input impedance to signal currents flowing into the base connection. Furthermore, the voltage drop from base to emitter necessary to make the transistor fully conducting also is very low because of the high transconductance of the device. If the signal sources are voltages—as is the usual case—then, to be able to apply two or more input sources with a minimum of cross-coupling, it is necessary to connect a relatively large resistance from the base to each signal source.

With zeros present at all inputs of this circuit, the collector emitter junction may be considered to be virtually an open circuit. Under this condition, current is coupled to the load through the collector resistance cap R_C . This condition is designated the logical 1 state, and now it is seen that this circuit has the basic requirements for a NOR function device.

After becoming familiar with the input and output power requirements of the control system, Delco Radio engineers chose about a tenth of a watt as the power level for logic operations. At this level the d-c power requirements for the logic are relatively small, thereby simplifying power supply design. Yet the output signals obtained can be readily amplified to useful output power levels.

The Delco transistor most suited to this power handling capacity is an audio driver unit originally developed for use

with portable radios. This unit is a PNP germanium type having high gain and low collector emitter saturation voltage. Its frequency response approaches 25,000 cps, which is adequate for use in static machine control systems.

After the basic transistor type was chosen, engineers determined the allowable gain variation and high temperature leakage. A circuit analysis of the NOR circuit made by Rowe and Royer² led to the following design equation for NOR circuit parameters:

$$N = \frac{-V_{CC}}{R_C} \left(\frac{1}{S I_b + I_t + \frac{0.25(M-1)}{R_1}} + \frac{R_1}{V_{CC}} \right)$$

where

- N = maximum number of logic inputs which can be loaded on a NOR output
- V_{CC} = collector supply voltage
- R_C = collector load resistance
- I_b = base drive current for complete conduction
- S = aging factor
- I_t = reverse bias current required to cancel collector-base diode leakage current
- M = desired number inputs to a NOR
- R_1 = input resistance.

Since this design relation involves many parameters, it becomes necessary to make measurements on the basic transistor type to determine which parameter values are indicative of a high yield and consequently low cost transistors. Studies were made on quantities of this unit to determine collector-base diode leakage as a function of temperature, supply voltage, and aging. The

results showed that the leakage was well under one ma at 75°C with diode voltages of 20 volts for a great majority of units. With this factor determined, it was necessary to make a practical choice for the parameters N , R_C , I_b , S , V_{CC} and R_1 , and then solve the design equation for I_b . This solution determined the minimum gain required for the transistor element in consideration of all tolerances and aging factors.

The choice of the collector and bias supply voltages nominally was made at -12 volts and +6 volts, respectively. However, the regulated supply voltages are governed by the actual values of the reference elements in the power supply. The closest standard zener diode voltages available were 12 and 5.6 volts. Zener diodes having a ± 5 per cent tolerance then were specified.

After examining many machine control systems and consulting with designers of controls, Delco Radio engineers decided that four logic loads should be the maximum. After a nominal choice of $R_1 = 1,800$ ohms, the design equation was solved for I_b :

$$I_b = -\frac{1}{S} \left[I_t + \frac{0.25(M-1)}{R_1} + \frac{V_{CC}}{NR_C} + R_1 \right]$$

Assigning the limit tolerance values under the most unfavorable conditions for the terms of the bracketed expression led to a design value of $I_b = 0.00075/S$. If an aging factor of 2.5 is assigned, the base drive current is specified as 0.3 ma.

Subsequent examination of the transistor test group for this value of base current after 1,000 hours of 85°C aging showed a yield of 50 per cent. Although this result was thought to be somewhat low, the engineers believed that the yield could be improved eventually. The so-called "worst" case limit tolerances referred to were low limit collector voltage, high limit bias voltage and a 7-per cent increase of R_1 and R_C which are nominally 5-per cent types. Test NOR circuits then were built to duplicate the actual worst circuit parameters for both states of NOR units over a temperature range of -40°C to +70°C. Measurements were taken which confirmed the adequacy of circuit design for the specified transistor.

Tests of NOR function devices in self-checking circuit configurations have

been temperature cycled continuously since December 1959. No failures have occurred over the specified temperature range.

Other Design Problems: Related Components and Physical Arrangement

The next major step in the development of the static control system was the over-all mechanical design including selection and arrangement of related components such as timing circuits, power amplifiers, and power supply. To meet the needs of application in industrial plants, Delco Radio engineers adopted the following design objectives:

- (a) Use individual control elements to provide maximum flexibility
- (b) Make control system wiring integral with logic elements
- (c) Mount all elements to provide for easy removal from standard enclosures (Joint Industry Conference type)
- (d) Keep power wiring separate from control wiring
- (e) Provide reasonable protection from environmental conditions, such as dust, humidity, corrosion, mishandling, shock, and vibration.

Circuit Boards

Earlier types of static control systems were built up in conventional electronic type rack mountings. Logic circuits used printed circuit boards with connectors attached to one edge. This arrangement was awkward for plant use because of the location of the logic wiring.

Delco Radio engineers studied various forms of packaging and wiring. It was decided to mount the control system elements on individual circuit boards as follows (Fig. 10):

- NOR board—containing two NOR functions
- MEMORY board
- Timer board
- OR board—containing two 4-input diode OR networks
- OR power amplifier boards—20 watts
- NOR power amplifier boards—20 watts
- Power amplifier board—50 watts.

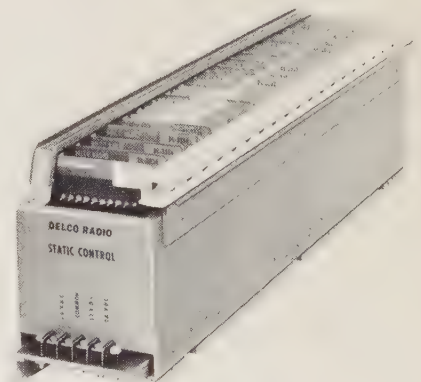
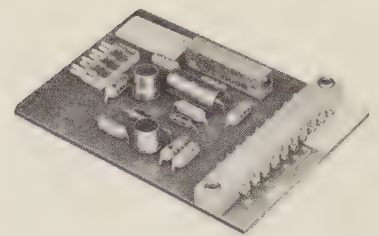


Fig. 10—The static control system is built up using appropriate circuit boards (top), in mounting racks as illustrated here. The over-all size of the rack is approximately 16½ in. by 4½ in. by 3½ in. The circuit board shown contains a timer circuit. Each board has taper pin connectors at the top for logic connections and a base connector at the bottom to plug into the power supply lines. These power lines are formed with printed wiring which extends over the length of a rack and terminates outside at screw terminal strips. These views show how the circuit boards are mounted for compactness, accessibility, and protection. Several racks may be used in a typical machine control.

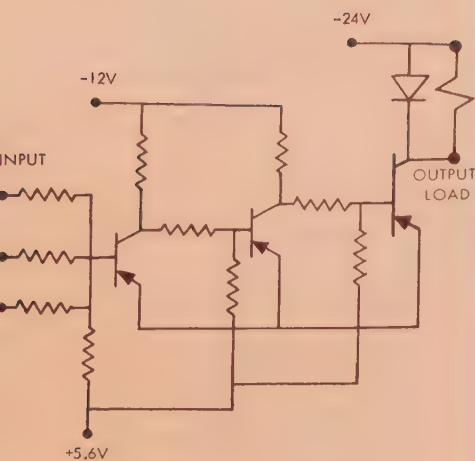


Fig. 11—This is the circuit for the 20-watt amplifier. The first stage and the output stage are biased below cutoff, providing a full driving signal into the second stage and turning it on. Since the output stage is coupled directly to the collector of the second stage, it receives no drive when the second stage is conducting. The output load is the collector impedance of the output stage, and receives no current for 0 signals into the first stage. With three possible inputs, this power amplifier performs a 3-input OR function since any 1 signal at an input causes a reversal of state for each stage of the power amplifier. A diode rectifier is connected in shunt with the load to absorb surge voltages caused by rapid turn off of load current.

Timing Circuits

Examination of typical timing functions required for machine controls such as time delay energizing, time delay de-energizing, time period, and delayed time period showed that a basic timed period element in conjunction with basic logic functions could accomplish any timing function.

The range of timing values associated with production rate operations is about 0.1 to 5 second. This timed period element is described as a pulse triggered one-shot multivibrator. The input signal is coupled capacitively to allow triggering from initiating logic signals. The output from this circuit is a negative voltage pulse or logical 1 having a preset duration in the range of 0.1 to 5 second depending on the values of the circuit resistance—capacity time constant.

Power Amplifiers

The power output requirements for most static control applications seldom

exceed 50 watts. This value is about the practical maximum of power that should be handled on a printed circuit board with switching circuits. This power is sufficient to operate most solenoids and solenoid valves, clutches, brakes, and contactors. The power stages should operate from a separate supply so that the regulation of the logic supply voltage is simplified. A 24-volt, d-c supply for the power stages was chosen in view of the desire for maximum reliability and the general availability of 24 to 28-volt, d-c load devices. With this 24-volt power supply, good design practice indicated that the power transistors should have a rating of 50 volts. This capacity was used, and extensive life testing of the power amplifiers showed that this was a proper selection.

The power amplifiers are made in a 20-watt and a 50-watt rating. The circuit for the 20-watt amplifier is a three stage design (Fig. 11). The 50-watt amplifier is of similar design, differing mainly in the second stage transistor which has a greater power rating. For control system simplification, a 20-watt NOR power amplifier is available to replace the OR power amplifier when inverse signal inputs are available.

Control System Input Devices

The choice of compatible input devices to indicate machine conditions for static control is a controversial subject. Many people feel that for those processes for which static control is being considered to decrease the production down time, static sensing devices also should be specified. Of course, this is desirable. But, unfortunately, such devices have not generally reached the performance levels possessed by mechanical switch devices.

The life and reliability of input switches of all types, especially limit switches, usually have caused engineers concern. In present relay machine controls, the switch often is required to carry heavy contactor or valve currents. Although the switch is rated to handle this inductive load, its life generally is limited by the wear of the switch contacts. In certain cases this switch current can be reduced by interposing a relay to handle the load current. This means additional expense and does not necessarily achieve a great increase in over-all reliability.

One of the principal advantages of static control is the tremendous increase

in switch life. This is mainly because the switch handles only a few mils of current or roughly 1/1,000 of its rating.

Early in the development of the Delco Static Control, GM Manufacturing Development, at the request of Delco Radio engineers, made studies to determine the optimum voltage and current for limit switches. This study showed that the full mechanical life of the switch is realized for a d-c switch voltage in the range of 100 to 150 volts and currents of less than 10 mils. This voltage range is superior to lower voltages due to its increased ability to burn away any high resistance oxide forming on the switch contacts. The tests further established that many types of industrial limit switches have a mechanical life of 50 million operations.

A full mechanical life is realized, however, only when the switches are mounted and actuated properly. Furthermore, if oily, dirty, or moist conditions prevail, sealed switches must be specified.

Photocell units of the photoconductive type provide a signal which is sufficient to drive a NOR element directly without preamplification. This feature eliminates a cumbersome relay amplifier normally required for machine control. Sensitive pressure switches and probe contacts also work without need for additional amplification.

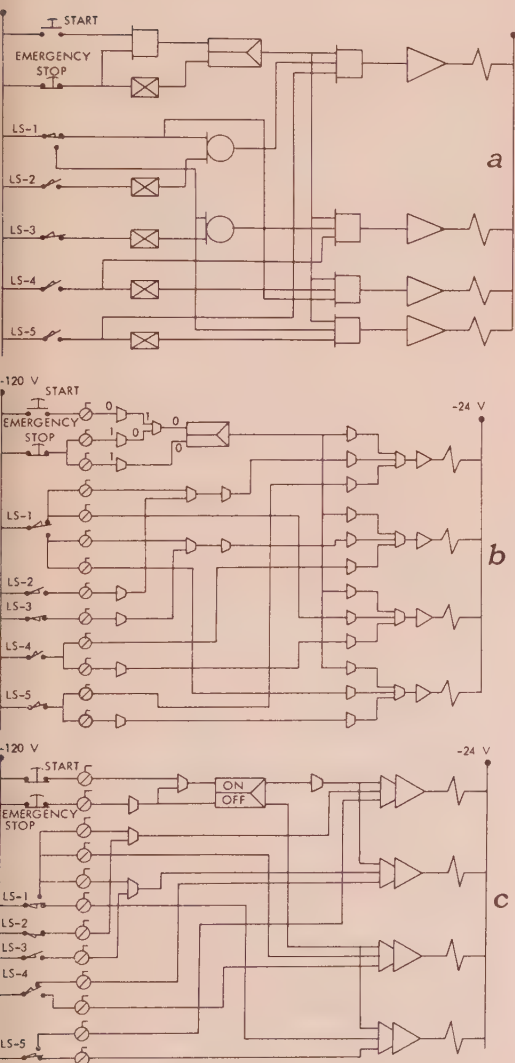
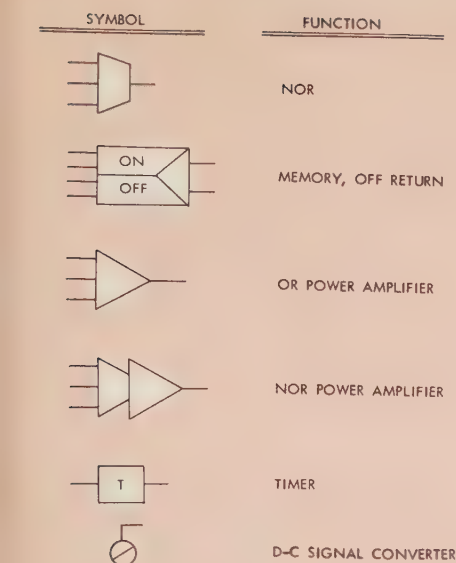
Power Supply

Semiconductor components are used throughout the power supply for rectification and control and to furnish voltage references. Delco high power rectifiers are used for the higher current requirements of the 12-volt and 24-volt sections.

Both the 5.6-volt and the 12-volt outputs are regulated against line voltage variations of 100 volts to 130 volts a-c and the full range of loading. The 12-volt section uses a one-stage transistor regulator following a zener voltage reference element. The 5.6-volt d-c bias voltage is supplied directly from a zener reference circuit.

Two other transistors in the power supply of the unit are used in conjunction with relays for safety interlocking circuits to prevent system malfunction.

The high voltage for exciting switch input devices is obtained by rectifying the output of an isolation transformer. This voltage is nominally 120 volts d-c. It varies, somewhat, since no regulation is necessary.



To prevent false operation of the MEMORY and timer elements, the 120-volt potential is applied to the machine switch circuits when power is initiated. A time delay relay circuit then allows a one-second delay before applying collector supply voltage to the normally off sections of memories and timers. The relay also breaks the 24-volt, d-c supply to power amplifiers to prevent false operation of load members during the delay interval.

To protect against the loss of the 5.6-volt d-c bias voltage, a transistor is connected in parallel with the time delay relay and biased to non-conduction by the bias voltage. If this voltage falls below three volts, the time delay relay will be de-energized and the equipment consequently will be de-energized.

The time delay relay interlocks the line holding relay circuit. This circuit consists of a transistor with a relay in the collector circuit which obtains excitation from the output side of the time delay relay. For normal line voltages (above 100 volts, a-c) the transistor is forward biased, allowing the relay to be energized. The contact on this relay is in series with the input a-c line. If the line voltage drops below 90 volts a-c, the transistor turns off and drops out the line holding relay. In addition, a thermostatic switch in series with the input line opens at 160°F to prevent possible erratic operation of the system at elevated temperatures.

Designing the System

Engineers designing a machine control

Fig. 12—Typical steps in developing a static control using the Delco NOR logic element are indicated in this example, which was applied to a vertical broaching machine. Diagram symbols not identified previously are shown at the top. LS denotes a limit switch. A control system designer starts by making a basic logic diagram showing the actions needed (a). In this case the circuit has 7 switch inputs, 13 logic elements, and 4 power amplifiers. This circuit can be simplified, however, by substituting NOR logic elements for the AND, OR, and NOT elements (b). The MEMORY element remains. Diagram (c) shows the final step taken to further simplify the control circuit. This is done by following the procedure outline in the text except that the Emergency Stop input is not by-passed. (A normally open switch contact is a poor safety practice.) Since a MEMORY function permits a maximum of three outputs on either section, two of the NOR loads on the output of the MEMORY ON section are eliminated by taking a signal from the output of the OFF section. The result is a control circuit using 5 NOR elements, a MEMORY element, and 4 NOR amplifiers. Such a circuit requires less than 8 circuit boards and only 15 transistors, exclusive of the power supply.

system can use various methods to arrive at a final logic system. Boolean algebra, if properly employed, can be used to completely synthesize circuit design. However, if time functions and memory functions exist in a control system, this approach becomes somewhat precarious and is not necessary. Many designers find it helpful to make up the relay-switch circuit for a control system from which a basic logic diagram can be derived. Once this has been done, conversion to NOR equivalents is easy. A representative problem for controlling a vertical broaching machine demonstrates this approach (Fig. 12).

A more detailed example of how a static control system is developed for a production machine is presented in a separate paper beginning on page 22 of this issue.

Summary

The transistor has several properties of interest to the engineer: it has no moving parts, it is small and light weight, it consumes little power, it can replace a switch or a proportional amplifier, it can perform logic, and it is reliable. Thus, transistorized switching circuits appear to be ideally suited to the control of high cycle machine operations.

The versatility of the NOR element in performing logic gives the Delco Static Control advantages over conventional relay and static control circuitry. With proper application, this control method offers to the user the benefits of faster cycling speeds, less maintenance, less down-time, and more reliability.

Bibliography

1. CALDWELL, S. H., *Switching Circuits and Logical Design*, (New York: John Wiley and Sons, Inc., 1958).
2. ROWE, W. D., and ROYER, G. H., "Transistor NOR Circuit Design," *A.I.E.E. Transactions*, Vol. 76 (July 1957), pp. 263-67.

Acknowledgement

The author acknowledges the contributions to the circuit designs of the static control elements made by J. E. Calabro, P. Ruepp and K. L. Stahl and the contributions to the mechanical design made by A. E. Vyzral and F. W. Whitford. Many valuable suggestions also were made by S. F. Newman of Manufacturing Development, GM Manufacturing Staff.

Application to a Hypothetical Production Machine

The principal components of the transistorized *Delco Static Control* are circuit boards which contain circuits for amplifiers, timers, and logic functions such as NOR and MEMORY. Applying these circuit boards, along with other necessary devices, to a particular machine control problem becomes the task of the control designer. To do this, he starts with a clear statement of the machine sequences, actions, and control functions expressed in logic symbols. With proper analysis of the basic control function circuit, he can simplify the circuit by using NOR logic elements. The result is a machine control system that has a minimum number of components and does away with the maintenance problems in conventional relay-switch control circuits. Currently, there are more than 1,000 circuit boards operating in several Delco Static Control systems installed in GM plants. No logic circuit failures have been reported from these applications.

MANY of the machines used in industry today are becoming more complex and more dependent on efficient, automatic control systems. As the complexity and speed of control decisions increase, the number of components in the control system increases more than linearly. Machine controls, as referred to in this paper, are those devices that control air cylinders, hydraulic cylinders, magnetic clutches, and brakes. These controls are used on machines that assemble, stake, press, weld, and otherwise bring together several parts to produce a finished assembly. These machines, operating on cycles of three seconds and less, may produce up to four million parts per year when operated 16 hours per day for 200 days per year. This means that each control component might go through many millions of cycles during the expected life of the machine. It is apparent that any control component that has moving parts subject to wear and friction is at a disadvantage when compared to the silent, motionless switch—the transistor. Thus, in an effort to improve machine performance and reliability of automatic controls, engineers at Delco Radio Division have developed a transistorized static control that is without moving parts. It is identified subsequently in this paper as *Delco Static Control (DSC)*.

The preceding paper, beginning on page 14 of this issue, discussed in detail the design and function of NOR, MEMORY, AND, and OR logic elements as well as amplifiers and timers¹. A knowl-

edge of these devices is applied by the control system designer to develop a static control for a production machine.

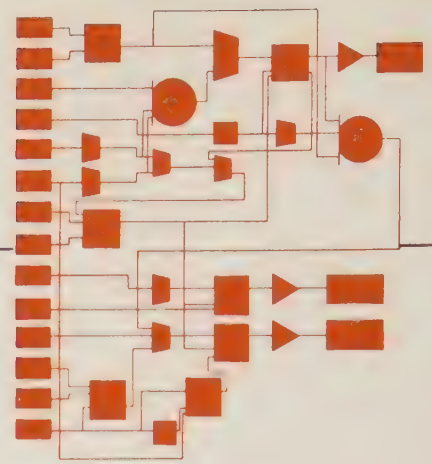
Since the application of the Delco Static Control can best be demonstrated by an example, a hypothetical machine control will be designed using the following procedure:

- (a) Constructing a table using a flow diagram and word statement of the problem
- (b) Drawing the functional control circuit using logic symbols
- (c) Analyzing and simplifying the circuit
- (d) Converting to NOR logic and laying out the final circuit.

Listing the Machine Sequences and Actions

The *flow diagram* is a sequence technique developed recently by Manufacturing Development, GM Manufacturing Staff². The heart of this technique is the flow diagram symbol, which is used to indicate the direction in which a machine member is operated and the member's position in the machine operating cycle (Fig. 1).

The control design problem involves a machine having a rotating table that must be indexed and two, air powered operating heads that must be moved up and down at the proper cycle times. This machine can be represented on a flow diagram, which usually is furnished by the mechanical designers responsible for



the over-all machine (Fig. 2). The flow diagram shows that the first control operation is to index the rotating table by energizing a clutch and de-energizing a brake. When the table indexes a designated number of degrees, a cam initiates a limit switch (1LS) and the table must be stopped by de-energizing the clutch and energizing the brake. Next, two air cylinders (Stations 1 and 2) are energized by simultaneously activating two solenoids (Sol 1 and 2). The heads of the cylinders go down thus completing the second part of the sequence. Since there is no *dwell* function for the first cylinder (Station 1), the head must immediately return (Sequence 3 for Station 1). The

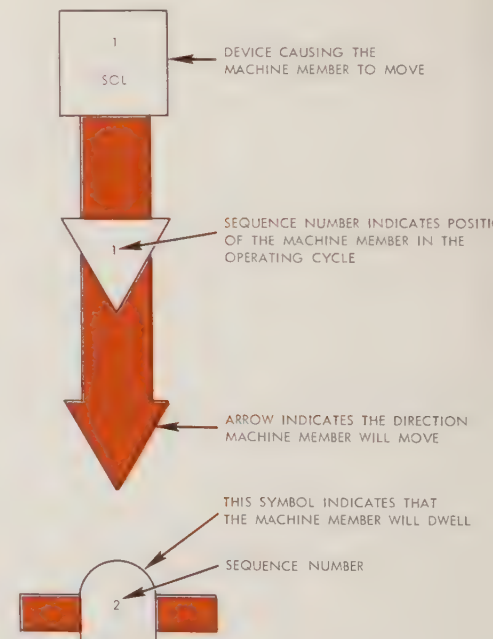


Fig. 1—Typical symbols used in preparing a flow diagram of a machine sequence are shown here. An actuating device, such as a solenoid valve, is placed at the tail of an arrow.

By HOWARD E. WRIGHT

Delco Radio

Division

How the control designer
analyzes the problem and
applies the devices

second cylinder has a slightly different sequence since a dwell function (number 3) is required when the head gets down. After the dwell, the head returns (Sequence 4) to complete the entire machine cycle. Another limit switch (6LS) is located so that it is actuated during an index. The purpose of this switch is to indicate whether or not a part was in the nest when the table indexed; this information controls the operation of the second cylinder (Station 2).

Some of the preceding explanation probably would not be necessary for the experienced designer since the flow diagram (Fig. 2) conveys most of this information. This flow diagram represents an automatic cycle only. Any deviation from this operation as required for set up or debugging operations is specified in the manual cycle.

The Word Statement

The word statement of the problem is a list of conditions and stipulations which determines the operation of the machine. When several conditions must be met before an event can be initiated, each condition is called an AND condition.

When any one of several conditions will permit an event to be initiated, these conditions are called OR conditions. Hence, a word statement is a list of AND and OR conditions. For convenience, a short hand symbol consisting of two letters is listed to the right of each word statement. These letters merely represent the statement. When a bar is placed above the two letter symbol, for example, CS, the meaning of the symbol is changed to the negative, or inverse, of the original symbol CS. If CS originally meant "the cycle has been started," \overline{CS} means "the cycle has not been started." The word

statement of the machine represented in the flow diagram (Fig. 2) is as follows:

	Symbol
Sequence 1 AND conditions to initiate the starting of the index cycle.	
1. Cycle start circuit initiated	CS
2. All heads returned	HR
3. Index table in position	OS
4. Emergency stop not actuated	\overline{ES}

Sequence 1 OR conditions to initiate the stop of the index cycle.

1. Index table in position	OS
2. Emergency stop actuated	ES
3. (a) All heads not returned	\overline{HR}
(b) Index circuit activated	IO

Condition number 3 under Sequence 1 (stopping of index cycle) is composed of two other conditions which are AND situations. When these two, \overline{HR} and IO exist simultaneously, they constitute one of the OR conditions which would stop the index table.

Sequence 2 AND conditions to initiate Head 1 down

1. Index completed	IC
2. Station switch on	SO
3. Emergency not actuated	\overline{ES}

	Symbol
Sequence 2 AND conditions to initiate Head 2 down	
1. Index completed	IC
2. Station switch on	SO
3. Emergency not actuated	\overline{ES}
4. Part in nest during preceding index	PN

Sequence 3 OR conditions to initiate the return of Head 1

1. Head forward	HF
2. Emergency actuated	ES

Sequence 3 OR conditions to initiate the dwell of Head 2

1. Head forward	HF
2. Emergency not actuated	\overline{ES}

Sequence 4 OR conditions to return Head 2

1. The proper time has elapsed	TO
2. Emergency actuated	ES

Some of the conditions listed above will be explained in more detail in this paper.

The Boolean Expressions

Before the next phase of the control design can be covered, a word is needed

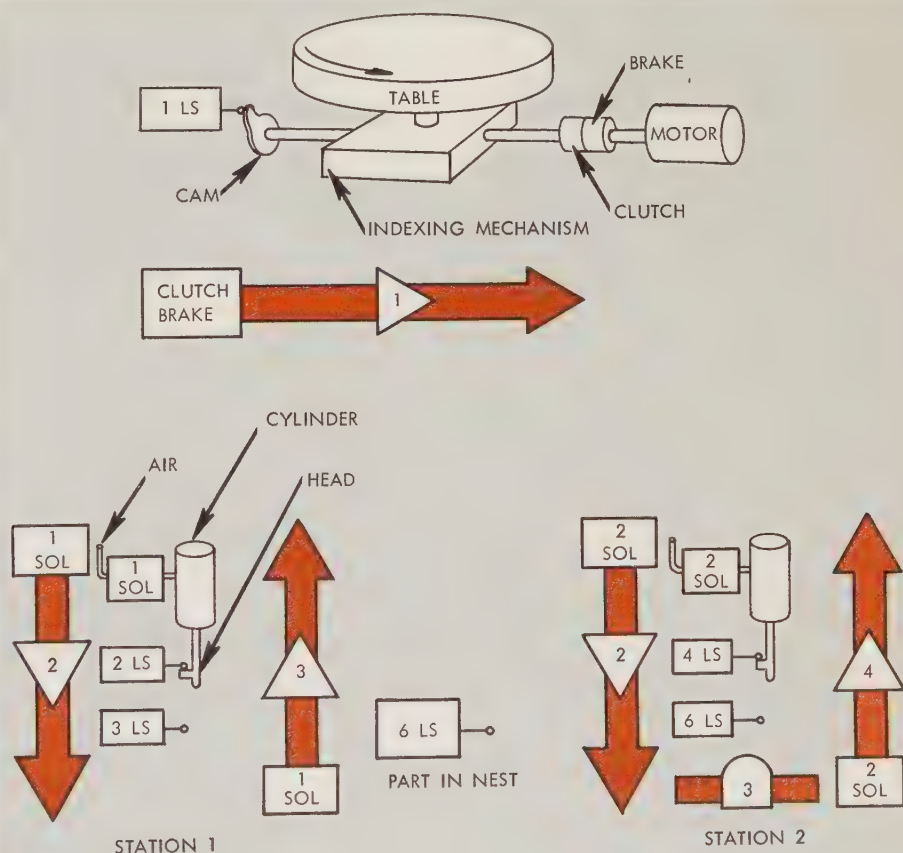


Fig. 2—This is a typical flow diagram which the control designer prepares to indicate the sequence of operation of an assembly machine. In addition to providing the sequence, the diagram locates and identifies limit switches LS, solenoid valves SOL, and other output devices such as the clutch and brake. This is the diagram for the automatic cycle of the machine used in the example discussed in this paper.

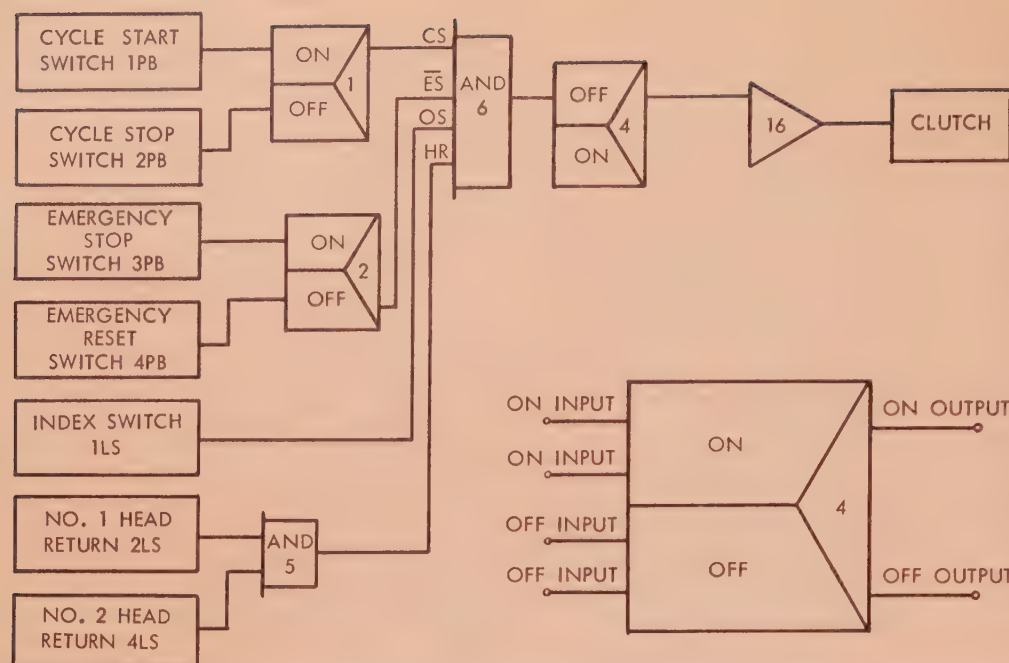


Fig. 3—The third step in the control design procedure is drawing a functional control circuit using logic symbols. Such a circuit is shown at the left. The Boolean expression $CS \cdot HR \cdot OS \cdot \bar{ES}$ indicates a four-input AND condition, which is shown at AND 6. The output is connected to one of the on inputs of MEMORY 4 and this on output goes to one of the inputs of amplifier 16. Generally, it is desirable to start an automatic cycle by initiating a push button. This would require some type of MEMORY, hence MEMORY 1. While it might appear that the emergency stop does not need to be a separate MEMORY (MEMORY 2), since the emergency stop signal could be connected so as to turn off MEMORY 4 directly, it is usually good design practice to use a MEMORY. In this manner, the MEMORY must be reset before the cycle can start once the emergency has been initiated. AND 5 is needed since there are two heads involved and one convenient way to indicate that both are returned simultaneously is to use an AND element. The boxes shown in color represent the mechanical input switches to the logic circuit. These are either limit switches or push buttons. Actual voltages and terminal points are shown in the final schematic used to wire the control.

about Boolean symbols and notations. A simple Boolean expression is $CS \cdot \bar{ES}$. The dot (\cdot) means AND so that $CS \cdot \bar{ES}$ is interpreted to mean CS and \bar{ES} are both required simultaneously to perform a function. $CS + TO$ means either CS or TO is required to perform some function. Using the \cdot and $+$ notation, the entire word statement of the design problem can be reduced to a few Boolean expressions. It should be noted that if the \cdot and $+$ are used in a Boolean equation, they represent multiplication and addition respectively.

The Boolean expressions can be arranged in the form of a table as follows:

- (1) $CS \cdot HR \cdot OS \cdot \bar{ES}$
Sequence 1, initiate start index
- (2) $OS + ES + (\bar{HR} \cdot IO)$
Sequence 1 initiate stop index
- (3) $IC \cdot SO \cdot \bar{ES}$
Sequence 2 initiate head 1 down
- (4) $IC \cdot SO \cdot \bar{ES} \cdot PN$
Sequence 2 initiate head 2 down
- (5) $HF + ES$
Sequence 3 initiate head 1 return
- (6) $HF \cdot ES$
Sequence 3 initiate head 2 dwell
- (7) $TO + ES$
Sequence 4 initiate head 2 return.

flow diagram and the word statement of the problem that when all the conditions stipulated in Expression (1) above ($CS \cdot HR \cdot OS \cdot \bar{ES}$) are met, the machine's table will index. To accomplish this, the clutch is energized and the brake de-energized. Since these conditions in Expression (1) generally exist simultaneously only for a moment, they probably would be connected to a MEMORY circuit. Delco MEMORY circuits are operated at too low a power level to drive the clutch and brake directly so that an amplifier is needed between the MEMORY and the clutch or other output

device. It is seen then that Expression (1) turns a MEMORY on and Expression (2) turns the same MEMORY off. Using the same reasoning, Expressions (3) and (4) turn on MEMORYs that energize the solenoids on the two stations. The energized solenoids then cause the heads to come down. Expression (5) turns off the MEMORY actuating Head 1 and Expression (6) turns on a time-delaying circuit. When this time delay has been completed, Expression (7) turns off the MEMORY holding Head 2 down, thus permitting Head 2 to return to its original position.

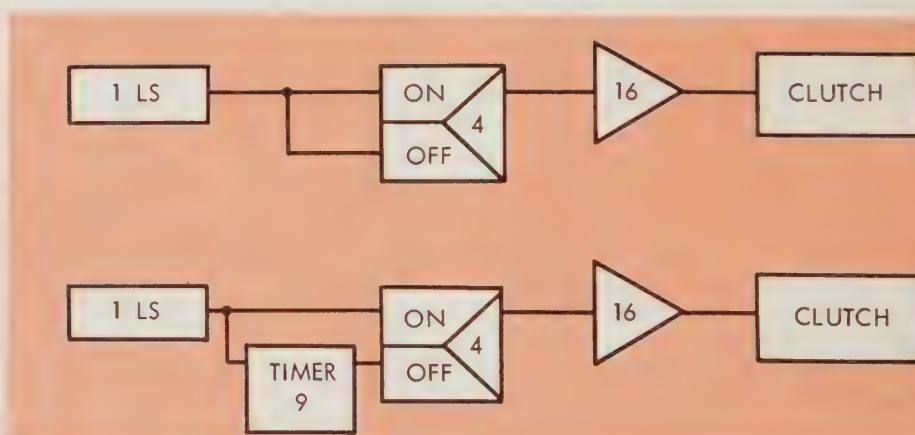


Fig. 4—The Boolean Expressions (1) and (2) of the control problem indicate that the same limit switch is required to both start and stop a machine motion. This situation is represented in the simplified circuit diagram shown at the top. Since a 1 input to both sides of a MEMORY produces a 0 output, the load never will be energized. To solve this problem, a timer circuit, as shown at the bottom, can be added. After the timed period—about $\frac{1}{2}$ second—the timer permits MEMORY 4 to be turned on. This permits the heads to start down but also protects against faulty cycle starts.

It is necessary to review the functions of the Delco Static Control components in order that the Boolean expressions in the above tabulation can be arranged into the next step of the design procedure—drawing the functional control circuit using logic symbols. AND circuits operate as follows: when a signal is applied to all input terminals simultaneously, an output signal appears at the output terminal as long as the stated input conditions exist. OR circuits have an output signal at the output terminal when any one of the input terminals has a signal applied. Again, the output of the OR exists only while the proper input conditions exist. It might be said that ANDs and ORs do not have any capacity to remember once the input conditions are removed. MEMORY circuits have this particular ability so that when a signal is applied to the proper input terminal, the MEMORY “turns on”—that is, a signal appears at the output terminal marked “on.” These MEMORY circuits continue to display the output after the input signal is removed. The MEMORY is turned “off” by applying an input signal to the proper terminal. When turned off, a signal appears at the off output terminal. MEMORYs also can be turned off by removing all power to the logic board. When power is reapplied to the MEMORY, the off condition always exists. It should be noted also that if a signal is applied simultaneously to both the on and off input terminals of a MEMORY, there is no output signal at either output terminal.

Timer circuits produce an output signal for a specified period of time when an input signal of any length is placed at the input terminal. Amplifiers are similar to ANDs and ORs in that the output exists only while an input signal is present. One other comment is needed about amplifiers and MEMORYs. The input circuits to these two devices are such that an OR condition is always present. This means that there are three input terminals to the amplifier and a signal at any one input is sufficient to drive the amplifier. The MEMORY has two sets of inputs—two to the on input terminals and two to the off input terminals. Again, the dual inputs to the on side and off side provide an OR situation for the designer which may save the use of extra components.

The output power of most DSC logic circuit boards is sufficient to drive four

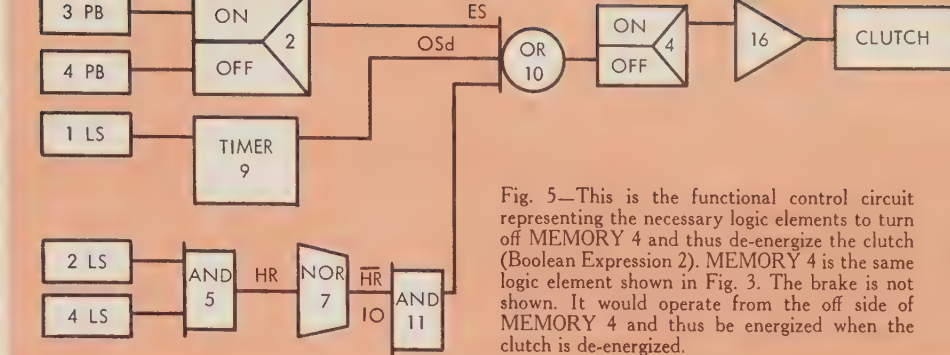


Fig. 5—This is the functional control circuit representing the necessary logic elements to turn off MEMORY 4 and thus de-energize the clutch (Boolean Expression 2). MEMORY 4 is the same logic element shown in Fig. 3. The brake is not shown. It would operate from the off side of MEMORY 4 and thus be energized when the clutch is de-energized.

other logic inputs simultaneously. The one exception to this is the MEMORY circuit. The on and off output terminals of the MEMORY circuit can drive three logic boards each. To discuss logic board operation, another notation is needed. A number 1 appearing at the input or output of a logic symbol means that a useful signal exists there. A zero (0) appearing at one of the terminals, however, means that no useful signal appears there.

Drawing the Functional Control Circuit Using Logic Symbols

The next step in the control design procedure is to draw the functional control circuit using logic symbols. This circuit contains diagrams which represent the previously stated Boolean expressions. Referring to Expression (1), it is evident that a 4-input AND condition exists. The output of the AND element drives the on side of a MEMORY which in turn drives an amplifier (Fig. 3). The AND element, identified as AND 6, has four inputs: CS, ES, OS, and HR. The output is connected to one of the on inputs of MEMORY 4 and the on input of this MEMORY goes to one of the inputs of amplifier 16.

Before completing the logic symbol drawing by developing Boolean Expression (2) which turns MEMORY 4 off, Expressions (1) and (2) should be examined further. Note that OS appears in both expressions. Remembering that Expression (1) turns MEMORY 4 on and Expression (2) turns the same MEMORY off, a conflict seems to exist. OS, which physically represents a limit switch, is being asked to both start and stop the index (Fig. 4). Remembering that a 1 input to both on sides of the MEMORY produces a 0 output, the load would never be energized. This problem can be solved by adding a timer circuit. Then, when the limit switch is initiated, MEMORY 4 momentarily has no output. After the timer (timer 9) times out, the MEMORY is turned on. Expression (2) can be modified to agree with this addition of a timer by representing OS as OSd (delayed OS). In actual use the timer would be set for about 1/2 second. This would be long enough to permit the heads to start down but short enough to protect against faulty cycle starts.

Another logic symbol drawing can be made representing Boolean Expression

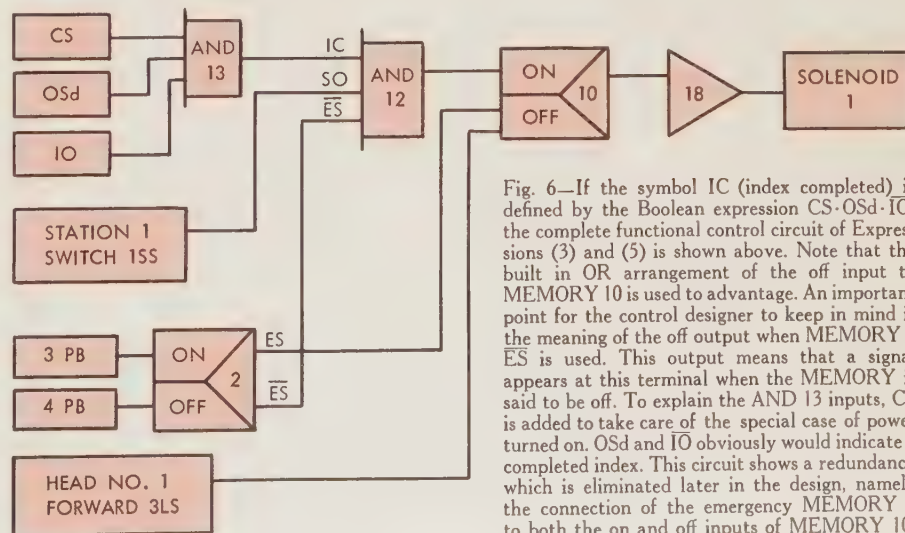


Fig. 6—If the symbol IC (index completed) is defined by the Boolean expression $CS \cdot OSd \cdot IO$, the complete functional control circuit of Expressions (3) and (5) is shown above. Note that the built in OR arrangement of the off input to MEMORY 10 is used to advantage. An important point for the control designer to keep in mind is the meaning of the off output when MEMORY 2 ES is used. This output means that a signal appears at this terminal when the MEMORY is said to be off. To explain the AND 13 inputs, CS is added to take care of the special case of power turned on. OSd and IO obviously would indicate a completed index. This circuit shows a redundancy which is eliminated later in the design, namely the connection of the emergency MEMORY 2 to both the on and off inputs of MEMORY 10.

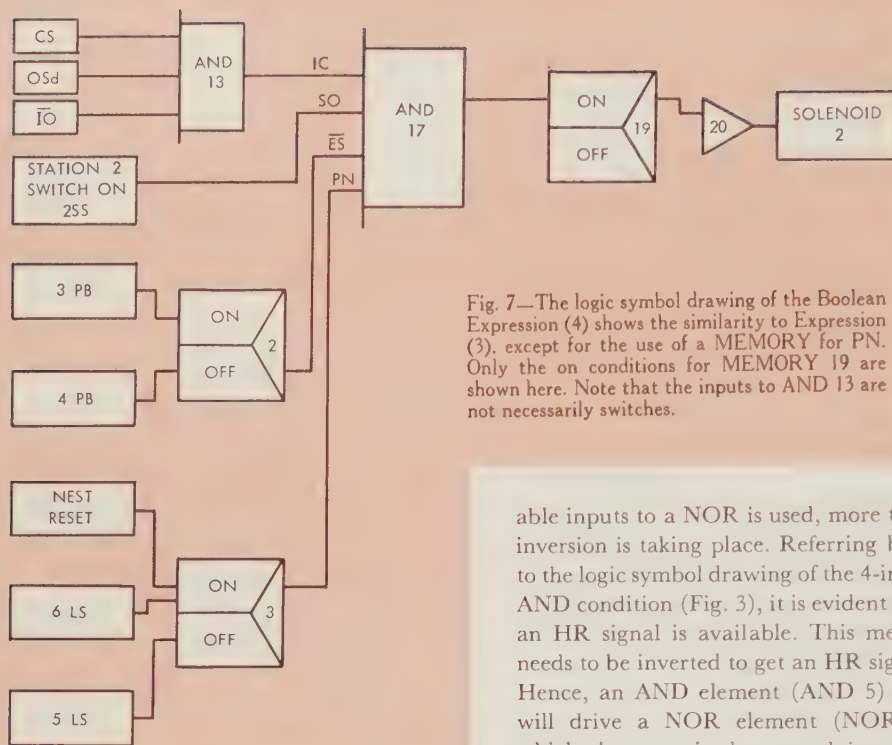


Fig. 7—The logic symbol drawing of the Boolean Expression (4) shows the similarity to Expression (3), except for the use of a MEMORY for PN. Only the on conditions for MEMORY 19 are shown here. Note that the inputs to AND 13 are not necessarily switches.

able inputs to a NOR is used, more than inversion is taking place. Referring back to the logic symbol drawing of the 4-input AND condition (Fig. 3), it is evident that an HR signal is available. This merely needs to be inverted to get an HR signal. Hence, an AND element (AND 5) also will drive a NOR element (NOR 7) which, in turn, is the second input to AND 11 (Fig. 5).

The next logic symbol drawing can be made for Expression (3), which brings down Head 1, and Expression (5), which returns this Head (Fig. 6).

Expression (4), which brings down Head 2, is identical to Expression (3) except for the symbol PN (part in nest during preceding index). A MEMORY element is used for PN in the logic symbol drawing (Fig. 7) for Expression (4). PN requires that the initiating circuit be actuated only if a part was in the nest during the preceding index. This function is performed by turning on a MEMORY when a part in the nest initiates the limit switch 6LS. The MEMORY is reset later.

The final logic symbol drawing is made for the last two Boolean Expressions (6) and (7), which initiate the dwell for Head 2 and the return of Head 2 (Fig. 8). This drawing shows that timer 14 delays the output of MEMORY 15 to produce the dwell. When MEMORY 15 has an output, it turns off MEMORY 19 which

returns Head 2 to its starting position and completes the entire machine cycle.

Analyzing and Simplifying the Control Circuit

After the control designer has completed the steps of preparing a flow diagram and word statement of the problem and has drawn functional control circuits, he can undertake the more interesting task of analyzing the over-all problem and searching for simplifications. In the case of the control problem for the machine described in this paper, a complete Boolean analysis is possible. However, this problem can be approached more easily by a reasoning technique. The relative simplicity of the problem and a familiarity with the Delco Static Control components makes this treatment possible.

For example, three changes can be made which simplify the functional control circuits described so far (Fig. 9). One change is the elimination of ES as a redundant function since ES was shown as one condition for turning on a MEMORY and ES as a condition for turning the same MEMORY off. The second change involves the circuit for Expression (2) containing the 3-input OR element (Fig. 5). In this circuit, the output of AND 11 turns off MEMORY 4. However, since MEMORY 2 also turns off MEMORY 4 and since the output of AND 11 could be considered an emergency condition (the head should not go down when the table is indexing), AND 11 is changed to drive MEMORY 2 (Fig. 9). This last change makes possible the third simplification of the circuit. OR 10 is left with only two inputs. This means that the OR element is not needed at all because MEMORY 4 has two inputs available on its off side.

Converting the Circuit to NOR Logic

Further simplification and final selection of the static control system com-

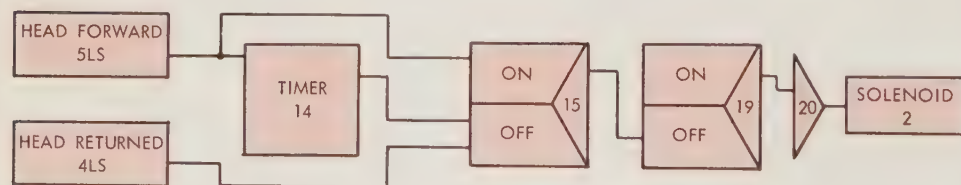


Fig. 8—The dwell and return conditions for Head 2 are represented by this logic symbol drawing for Expressions (6) and (7). Time delays are accomplished by the connections shown between 5LS timer 14 and MEMORY 15. When 5LS is initiated, a signal appears at MEMORY 15 on input and off input simultaneously since timer 14 also has an output when the switch is initiated. MEMORY 15's on output is not present as long as this condition exists. When the timer times out and 5LS remains closed, MEMORY 15 will turn on.

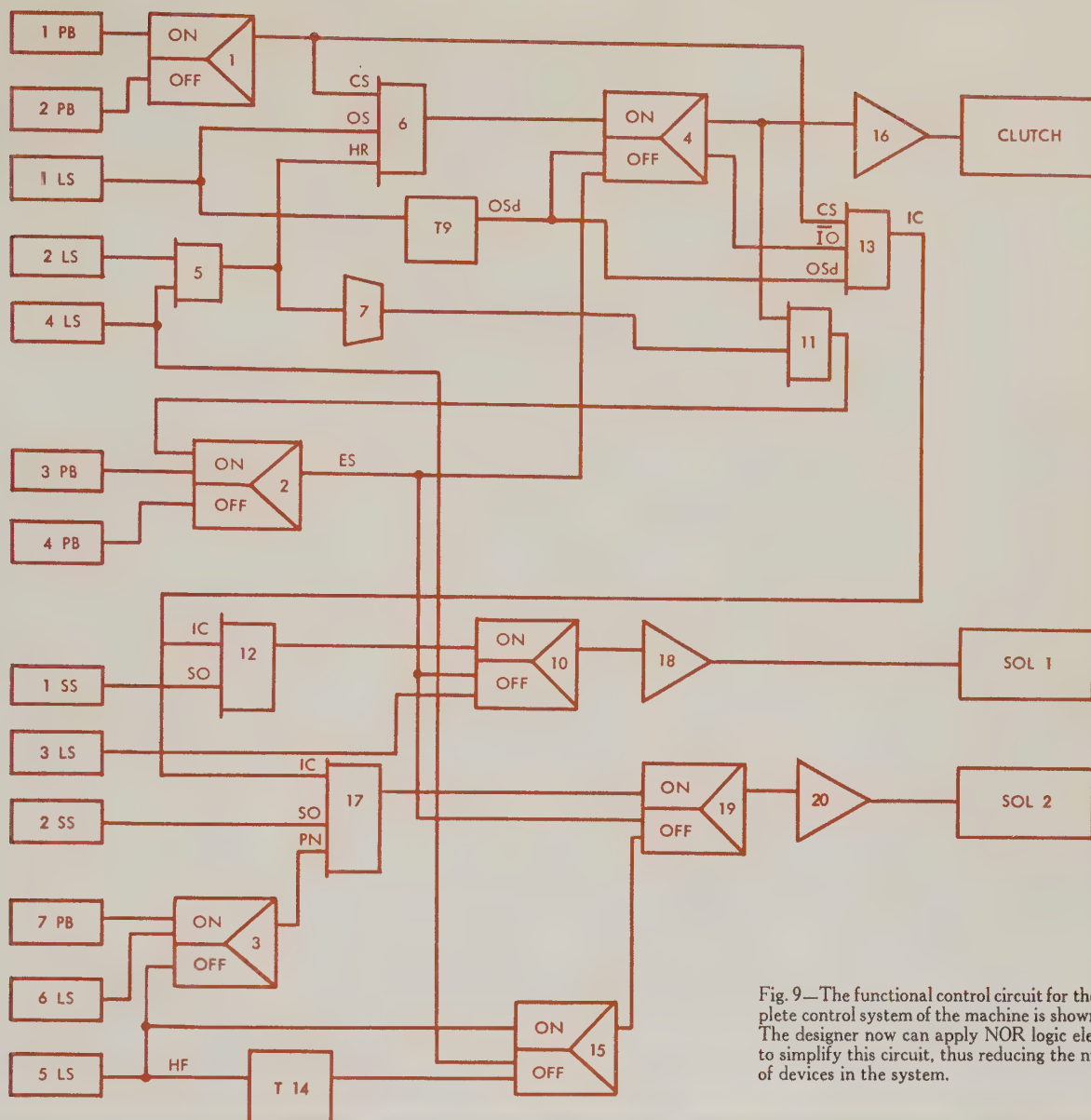


Fig. 9—The functional control circuit for the complete control system of the machine is shown here. The designer now can apply NOR logic elements to simplify this circuit, thus reducing the number of devices in the system.

ponents is accomplished by applying the Delco NOR function circuits—the final step in the control design procedure. All of the AND elements shown in the functional control circuit can be represented by a combination of NOR circuits (Fig. 10). In this arrangement, three NOR elements, 1a, 1b, and 2a, receive inputs, and their outputs, in turn, go to the inputs of a fourth NOR element 2b. Remembering that an AND element has an output only when a 1 signal is present at all inputs simultaneously, the outputs of NORs 1a, 1b, and 2a (which are 0 when 1 inputs are present) are inputs to NOR 2b. Only when all the inputs of a NOR are 0 is the output 1. Since NORs 1a, 1b, and 2a merely serve to invert the 1 signal presented to their respective inputs, another simplification becomes

possible. If the switch or logic device that is creating the 1 input to these NORs can be inverted, then the intermediate NORs are not needed.

Further analysis of the functional control circuits reveals other features of the NOR element which add to its versatility for use in static control systems (Figs. 10 and 11).

The last major simplification can be made by considering three AND elements: AND 13, AND 12, and AND 17 (Fig. 9). By using the inverse input method, two of the three input NORs of AND 13 are eliminated. This means the inputs are \overline{CS} , \overline{IO} and \overline{OSd} . Since AND 12 and AND 17 each have a common NOR input from AND 13, they are combined to produce diode OR 7b (Fig. 12).

The Final Circuit

The final circuit for the static control of the machine contains the addition of information such as components necessary for manual cycle operation, voltages, switch symbols, and signal converters (Fig. 13). Providing the manual cycle in this circuit requires no additional logic functions because of the OR input condition existing on DSC MEMORYs and amplifiers. The manual cycle is used for machine setup or trouble shooting work. When the HAND position is selected, the rotating table can be indexed or either of the machine heads can be lowered.

All of the limit switches that are likely to operate once each cycle are isolated; that is, they are not in series or parallel with other switches or relay contacts.

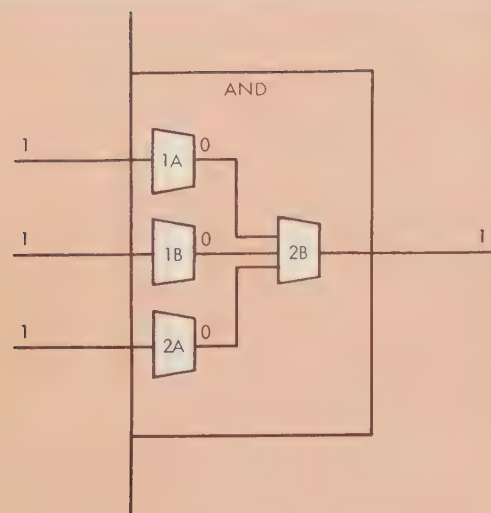
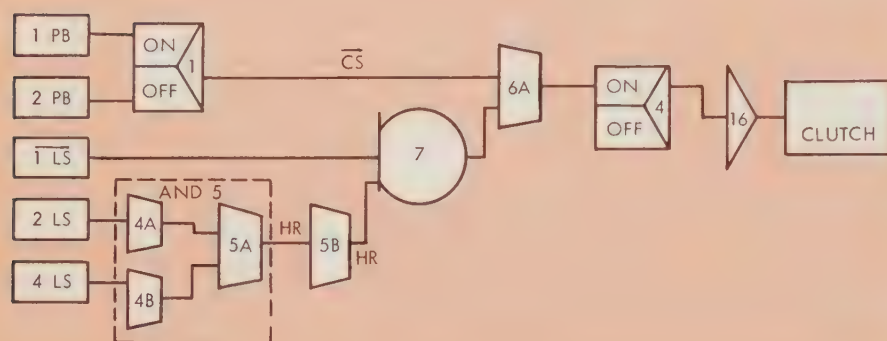


Fig. 10—One way to simplify static control circuit design is to substitute a combination of NOR elements for an AND function (left). The NOR element also is used to provide another feature in the circuit design. The three inputs to a NOR element can be expanded by merely connecting the output of a diode OR element to one of the inputs of the NOR. If the diode OR has four inputs then the NOR has a total of six inputs. Using this information, the 4-input AND circuit of Fig. 3 can be changed to the circuit shown below. This shows that NOR 6a was formerly AND 6. The AND 6 element can be represented by four NORs all connected to a fifth NOR as illustrated by the 3-input AND (left). Also, by using the inverse of the input signal where available, the intermediate NORs can be eliminated. A diode OR, (OR 7), added to NOR 6a provides the necessary four-input conditions of AND 6. The inverse of CS is available from the off side of MEMORY 1. The inverse of ILS is usually available and AND 5 can be inverted by adding NOR 5b.



This condition permits the use of a neon indicating light between the switch and common to give positive indication that the switch is operating.

A comparison of the number of NOR elements in the final circuit with the number of NORs required for the original functional control circuit (Fig. 9) illustrates how the circuit is simplified. The number of NORs has been reduced from 22 to eight plus two diode ORs. In addition, seven MEMORIES, two timers, and four amplifiers are used. The DSC circuit boards contain two NOR elements on one board and two diode OR elements on one board, which accounts for the use of the letters *a* and *b* when referring to NORs and ORs. Since the rest of the logic functions are placed singly on a circuit board, the total number of boards required for this machine control system is 18.

Some Installation Comments

A single DSC mounting rack is designed to hold as many as 20 assorted boards. Each rack requires 64 sq in. of

mounting space. The interconnection between boards is made by taper pins in individually identified receptacles. A wiring chute permits removal and changing of any board without disturbing the rest of the system programming.

The separate power supply requires 100 sq in. of mounting space and contains all the necessary voltages for operation of the logic elements and amplifiers. These voltages are regulated and interlocked so that loss of a voltage will shut down the system. The logic boards and power supply are designed to operate in ambient temperatures up to 160°F with an input line voltage fluctuation of 100 to 130 volts.

Since this static control is designed to replace relays used in fast, long lived operations, an interesting comparison can be made between the completed hypothetical design using static controls and an equivalent relay system. Such a relay system would require at least six relays and two timers. If only two sets of contacts on each of these mechanical devices were used, 16 operating contacts would be required. Thus, if the operating cycle is three seconds for a 16-hour day and a 200-day year, four million operations will occur on each set of contacts in a year, or a total of 64 million contact

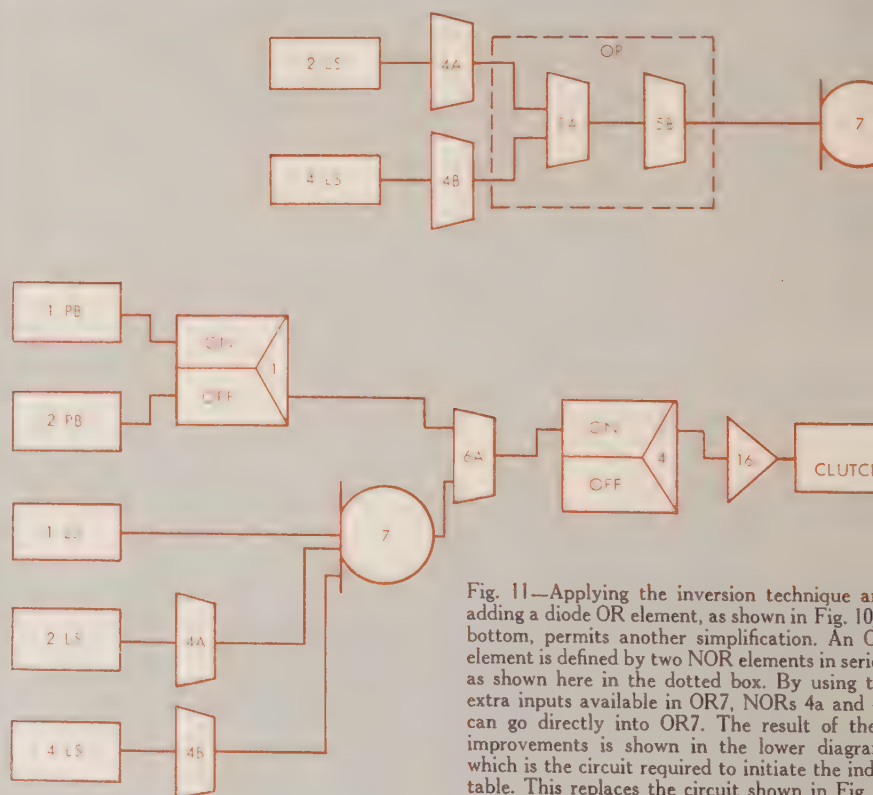


Fig. 11—Applying the inversion technique and adding a diode OR element, as shown in Fig. 10, bottom, permits another simplification. An OR element is defined by two NOR elements in series as shown here in the dotted box. By using the extra inputs available in OR7, NORs 4a and 4b can go directly into OR7. The result of the improvements is shown in the lower diagram, which is the circuit required to initiate the indicated operation. This replaces the circuit shown in Fig. 10.

operations in the system. About 10 million contact operations is considered a good life for these devices.

The static control system described in this paper has 36 transistors; thus, it would have 144 million transistor operations in a year. Life tests conducted at Delco Radio indicate that this kind of performance is reasonable. The tests have been underway since December 1959 with case temperatures and loading conditions more severe than the machine control would encounter. In this test, each of 20 transistor NOR circuits is

being turned on and off continuously at the rate of 60 cycles per second. This has produced over 1.5 billion cycles on each NOR circuit, or 30 billion transistor operations. No failures have occurred.

The operating speed of the components in the DSC system is less than one millisecond. The actual time required from the closing of a switch to the energizing of a solenoid valve depends on the number of intermediate boards. This time is negligible, however, compared to the time required to start an air cylinder or to bring an indexing table up to speed.

Conclusion

In addition to advantages such as fast operating speeds, no moving parts, small size, and ability to perform logic functions, the Delco Static Control offers two other benefits which involve the input and output devices. Much longer electrical life for the input limit switches has been proven to exist¹. This is because the switch controls a very small amount of power in a resistive load. The second benefit is that the performance of output devices, such as the coils of solenoid valves, is improved since they never

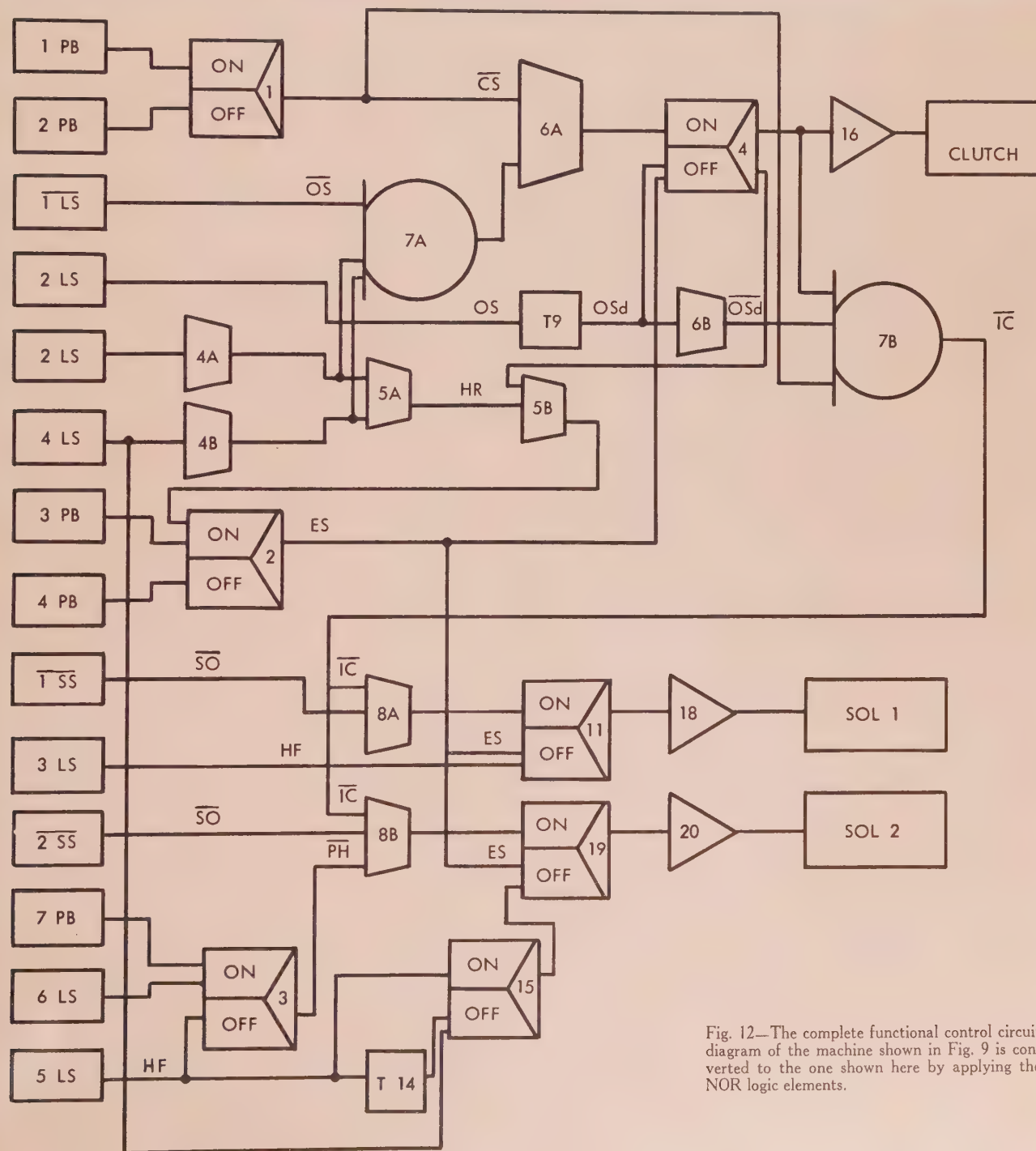


Fig. 12—The complete functional control circuit diagram of the machine shown in Fig. 9 is converted to the one shown here by applying the NOR logic elements.

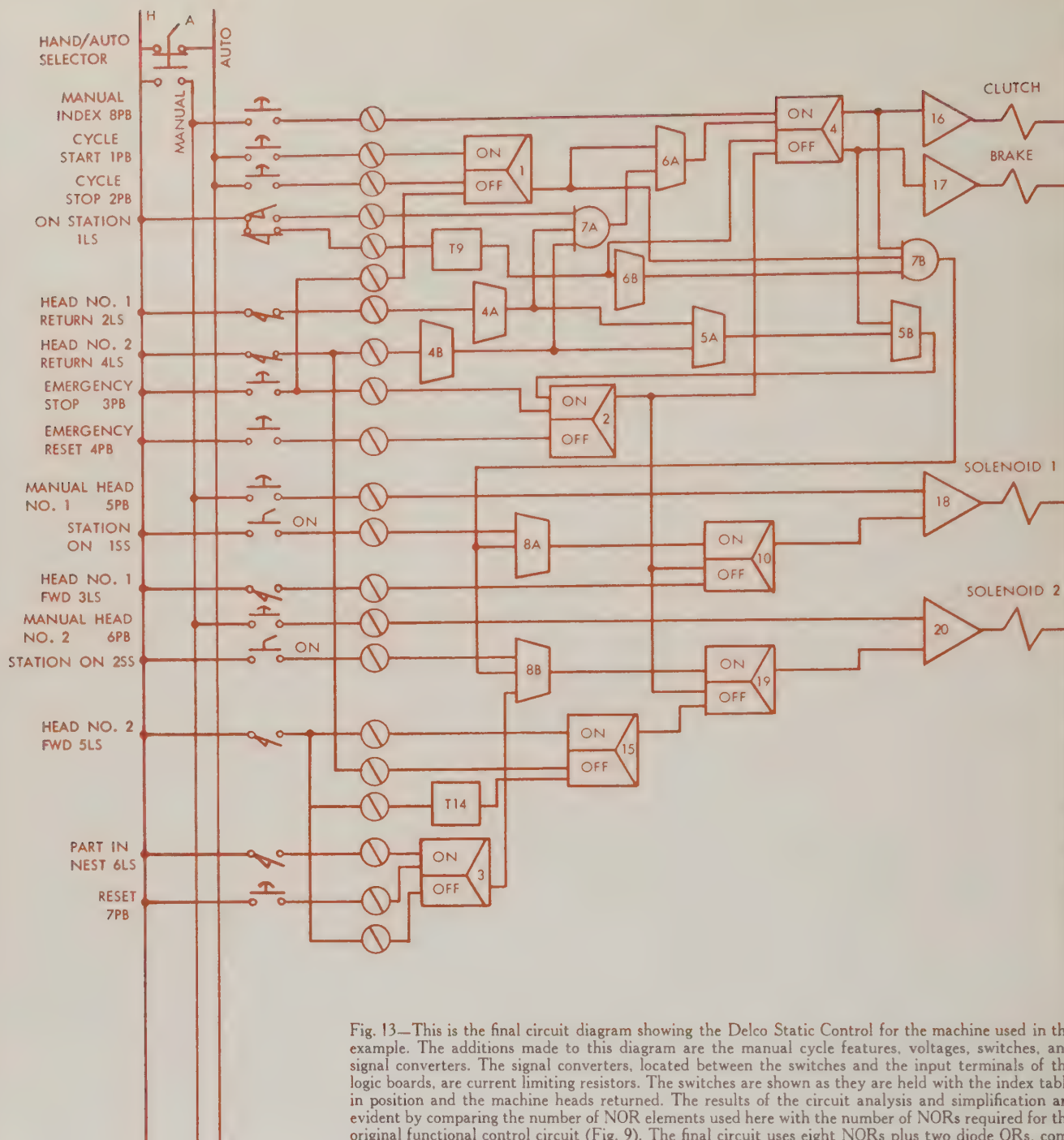


Fig. 13—This is the final circuit diagram showing the Delco Static Control for the machine used in the example. The additions made to this diagram are the manual cycle features, voltages, switches, and signal converters. The signal converters, located between the switches and the input terminals of the logic boards, are current limiting resistors. The switches are shown as they are held with the index table in position and the machine heads returned. The results of the circuit analysis and simplification are evident by comparing the number of NOR elements used here with the number of NORs required for the original functional control circuit (Fig. 9). The final circuit uses eight NORs plus two diode ORs, compared with 22 NORs required for the circuit of Fig. 9. Eighteen Delco circuit boards are used.

encounter large voltage transients that are set up by the sudden opening of relay contacts in an inductive load.

There are 15 Delco Static Control systems currently being used in several General Motors Divisions. The size of these systems ranges from one to eight racks containing the circuit boards. There are more than 1,000 logic circuit boards installed in these DSC systems,

some of which have been operating for over a year. No logic failures have been reported. The largest single DSC system developed so far (700 circuit boards) is being installed at Delco Radio Division.

Bibliography

1. WILSON, D. G., "Static Controls for Machines: Evolution and Design of

the Transistor Circuits," *General Motors Engineering Journal*, Vol. 8, No. 3 (July-August-September 1961), pp. 14-21.

2. CRAIG, JOHN E., "A Simplified Method for Showing the Operating Sequence of Complex Manufacturing Equipment," *General Motors Engineering Journal*, Vol. 6, No. 3 (July-August-September 1959), pp. 8-10.

How Roadside Ditches and Slopes Can Be Designed for Safety

By KENNETH A. STONEX
General Motors
Proving Grounds

The off-the-road accident, a problem on the nation's highways and on its own road system, impelled the General Motors Proving Ground to establish specific design criteria for roadside slopes and ditches. Analysis confirmed by a test program showed that the length of the vertical curve between the side slopes and the ditch bottom is the most important element in controlling the severity of impact of a car travelling through a ditch. Analysis of the force and moment relations, confirmed by tests of cars sliding on a roadside slope, related car stability factors with roadside slope and ground reaction coefficient, and led to quantitative statements of these relations. These tests showed that the effect of a roadside slope on the deceleration required to overturn a car is of the first order of significance. The analysis pointed out also that the low center of gravity height of modern automobiles has contributed most significantly to stability and resistance to overturning. The design criteria suggested by these results were applied in the construction of the R & H Loop, a recently completed test road on the Proving Ground near Milford, Michigan.

THE significance of the roadside in the highway safety problem is second only to the two-vehicle collision. National Safety Council statistics show that year after year about one-third of the highway fatalities in the country occur in non-collision accidents, most of which involve the vehicle leaving the roadway.

The problems of safe roadside design are of great importance at the General Motors Proving Ground at Milford, Michigan, where the safety of the employee is a primary consideration. In addition, General Motors is vitally interested in public highway safety from the standpoint of vehicle design, and in the promotion of better driving habits, traffic systems, and more adequate highways.

The Milford Proving Ground is essentially an outdoor road test engineering laboratory where complete vehicles and vehicle components are tested under controlled conditions on a private '65-mile road system containing all types of surfaces common to public highways. Since its inception in 1924, over 200 million test miles have been driven on the road network. The current rate is about 50,000 miles per day, or 12 million miles per year. These operations provide an unusual opportunity to study various types of highway safety problems and to make the results available for extension to the nation's highway system.

The roadside accident is of primary concern at the Proving Ground. Despite the careful selection and thorough train-

ing of test drivers, and the use of a road system with favorable geometry, low traffic volumes, controlled access, one-way operation, and close supervision, the Proving Ground had 170 off-the-road accidents during the last six years. The management of the Proving Ground felt that although this accident record was less than one-third of the rate for public highways, an improvement was essential. Therefore, a study of off-the-road accidents was made. The dual objective was to minimize the effect of such accidents at the Proving Ground and to obtain information about them which would be useful to local and national groups interested in highway safety.

The first and most obvious concern was to determine why drivers leave the road. Although driver training programs and good highway design help reduce off-the-road accidents, it was evident that drivers do leave the road at times since they are people and suffer such normal human fallibilities as sleepiness and inattentiveness.

The Proving Ground concluded that the design objectives of a highway should be not only to *avoid accidents*, but also to *provide safeguards* in the event a vehicle leaves the road because of human fallibility.

An analysis of the Proving Ground's road system showed that the traffic patterns and highway designs practically eliminated the possibility of two-vehicle collisions, and that the problem requiring

Probing off-the-road accidents—a problem in highway safety

solution was the off-the-road accident. The solution was to eliminate roadside obstacles and to reconstruct ditches and roadside slopes so they would be traversable and safe.

Ditch Tests Conducted to Evaluate Design Criteria

In most parts of the United States it is necessary to use ditches as a means of draining off surface water. While effective as a drainage system, these ditches frequently present a serious safety hazard.

Although ditches with flat bottoms, smooth contours, and flat slopes have been advocated frequently, no criteria were available to relate design with safety. Preliminary tests at the Proving Ground demonstrated that a car could be driven easily and safely at 60 mph through a ditch with a wide rounded bottom. It was not known, however, whether the slope and back slope, the width of the ditch bottom, or the depth of the ditch was the most significant factor in vehicle damage and occupant injury.

The Proving Ground, therefore, developed a mathematical analysis and conducted a series of tests to evaluate the severity of crossing a ditch as a function of speed and ditch cross section. The objectives of the tests were to verify the analysis and evaluate driver tolerance.

In the initial tests, a ditch was dug



Fig. 1—This schematic drawing shows the circular path of a car's center of gravity as it goes through a ditch.

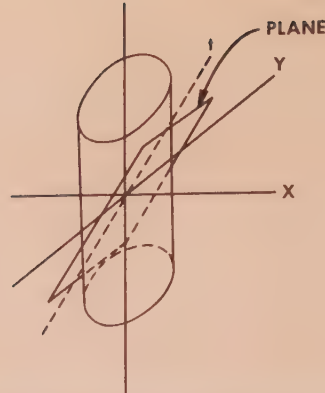
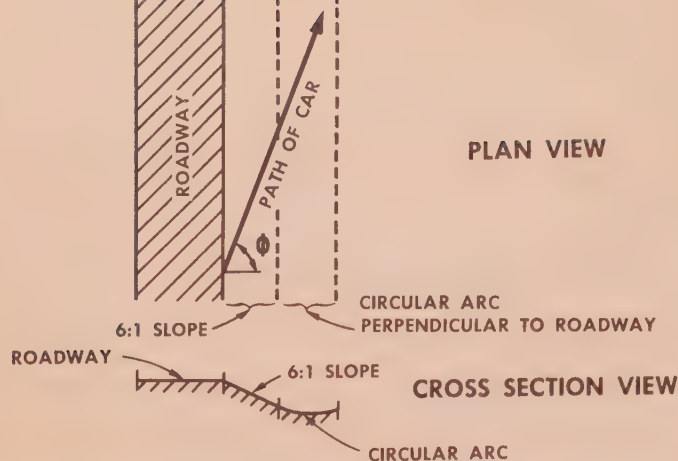


Fig. 2—At the left are a plan view and a cross sectional view of a typical ditch. A projection of the circular cross section of a car's path through the ditch is illustrated at the right.

according to standards of the Michigan State Highway Department for a median ditch on a divided road. Cars were driven through the ditch at moderate speeds. The driver noted the subjective severity as speed was increased. Measurements of vertical accelerations were made so that the numerical values could be correlated with the driver's sensations up to the point where the operation became so severe that it was unsafe.

The tests were continued up to the point of minor to severe damage by using remotely controlled cars at increasing speeds. By extrapolating these results, an estimate was made to ascertain where serious or fatal injury might be produced.

Intuition suggests that a ditch cross section should be of a curved nature to minimize impact such that, as the suspension system deflects under impact, the unsprung mass of the car follows a curved path. If the transition from the side slope to the bottom of the ditch is gentle enough so that the bumper does not dig in, the unsprung weight and the sprung mass of the car should have a continuous curvilinear motion (Fig. 1).

If a ditch cross section is circular with radius r , the projection on the path at which the car might run through the ditch becomes elliptical in form; the path will make some angle with the axis of the road, possibly up to 20° or more (Fig. 2 left). The projection of a circular cross section on a path at an angle of $90^\circ - \phi$ from the axis of the road has the mathematical form:

$$\frac{t^2}{r^2} + \frac{y^2}{r^2 \cos^2 \phi} = 1$$

which is an ellipse in the $y-t$ plane (Fig. 2 right), with major axis $\pm r/\cos\phi$, minor

axis $\pm r$, where $90^\circ - \phi$ is the angle between path of car and axis of ditch*.

With a given ditch cross section, the radius of curvature may be estimated graphically, and with the speed arbitrary, the value of the radial acceleration can be computed.

To verify the theoretical analysis and to develop values of radial acceleration or severity which could be tolerated, three ditch sections were constructed (Fig. 3). Typical values of the normal or vertical accelerations then were computed for the ditch sections (Fig. 4).

Angles of 10° , 15° , and 20° were laid out between the car path and axis of each ditch, and a car was driven through the ditches at increasing increments of speed.

*The derivation of this formula is available upon request.

During each test, recordings were made of the normal acceleration, and the driver's opinion of the impact severity was noted. Tests were conducted up to the point of extreme driver discomfort, then an estimate was made of the tolerable value of normal acceleration.

It should be noted that the trained test driver used in these tests probably developed a resistance to the severity of discomfort involved in this type of operation that a normal driver does not have. The unwary driver leaving the road probably would experience severe psychological damage before suffering physical injury. His reaction also might cause him to lose control of the car and precipitate an even more serious accident. Good design must look safe to retain driver confidence as much as possible.

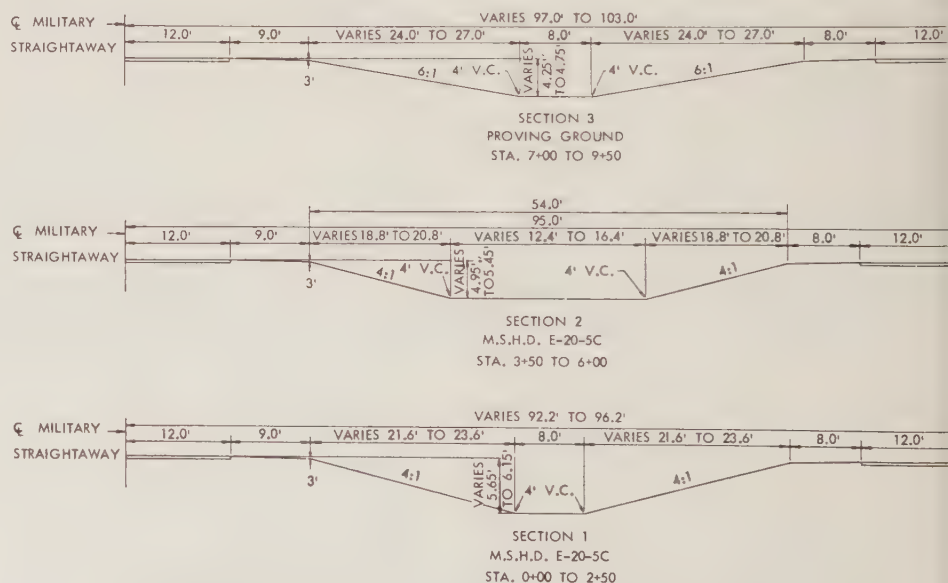


Fig. 3—Cross sections of the three ditches constructed for the tests are shown here. Sections 1 and 2 were taken from standards of the Michigan State Highway Department for a median ditch. They both have ditch slopes of 4 to 1 with varying width of the bottom and varying depth to provide longitudinal drainage. Section 3 has a slope of 6 to 1 with the depth varying from $4\frac{1}{4}$ ft to $4\frac{3}{4}$ ft.

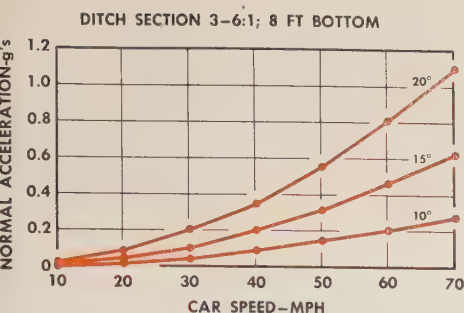


Fig. 4—This graph shows the normal, or vertical, acceleration calculated as a function of speed for a car going through ditch section 3 (Fig. 3) at angles of 10°, 15°, and 20°.

After the practical limit of driver tolerances had been reached, test cars were operated by remote control in a limited series of tests to determine, if possible, the severity at which structural damage appears. Since there should be no serious interest in ditch cross sections where the severity is beyond the driver's tolerance, these tests were not considered significant; they indicated that severity increases with speed in the manner suggested in Figs. 4 and 6.

The test data consisted of values of acceleration measured by a transducer carried on the car so that it measured the accelerations approximately normal to the longitudinal axis of the car and recorded them on an oscillograph. Car speed was recorded simultaneously (Fig. 5).

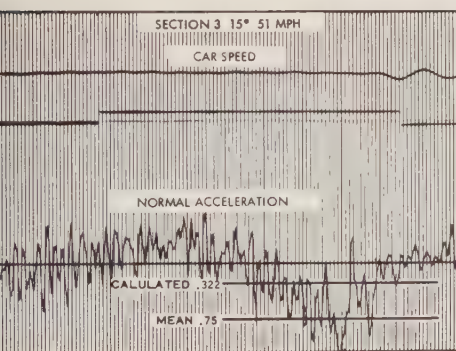


Fig. 5—This is a typical oscillogram showing the results of one of the ditch tests. The upper trace indicates the car speed, which in this case was 51 mph. The slightly elevated portion of the second trace represents the time the car was passing through the ditch as noted by the driver. The bottom trace records the acceleration normal to the longitudinal axis of the car. Notice that as the car enters the ditch the acceleration is slightly above the zero line, or negative, probably as the result of going over the vertical curve. The acceleration increases rapidly and during the most severe portion of the passage through the ditch it reaches a fairly high level which persists for approximately 0.2 sec. The mean value during this portion of the test was approximately 0.75 g, while the value calculated by assuming the reasonable path of curvature from the projected cross section of the ditch was 0.32 g.

The typical test result showed that the values of the measured acceleration fell in the range of the computed acceleration for only part of the test. Measured values approximately double the calculated values, however, persisted for an appreciable period (Fig. 6).

This result is easy to explain. The suspension system of an automobile will bottom under the values of vertical acceleration, which are relatively mild in the framework of reference for these tests. When a suspension system bottoms, vertical forces are transmitted through the rubber bumpers which have a rate that is variable and is much higher than car springs. Consequently, an impact severe enough to bottom the suspension system introduces non-linearities for which no provision is made in the computations.

Thus none of the three ditch sections tested would be acceptable for a road where speeds above 50 mph are anticipated.

Driving experience at moderate speeds indicates that the severity of impact becomes uncomfortable approximately at the point where the suspension bottoms; it approaches the intolerable level when the bumper strikes the ground. At higher speeds, it would be expected that even minor contact with the ground would produce injury. This is a condition which a ditch section design should avoid. There is some evidence that suspension systems bottom heavily under normal vertical accelerations of about 0.5 g. This is in the range in which the computed severity of operation is a first approximation to the average values observed.

The observations suggest some design criteria for ditch cross sections. The cross section, when projected at reasonable angles of attack, should yield vehicle path profiles such that the curvature of the path of the center of gravity is estimated with some accuracy. Also, it should be possible to calculate a first order approximation to vertical acceleration. Conservative design criteria should assure that calculated values of vertical accelerations do not exceed 0.5 g for a car passing through a ditch at an angle of 15° under the anticipated speeds of operation. This would allow reasonably comfortable operation at the design speed and would provide a slight margin of safety for the driver who exceeds the design speed and leaves the road at an angle of 15° or more.

The most important ditch design element in controlling the severity of impact

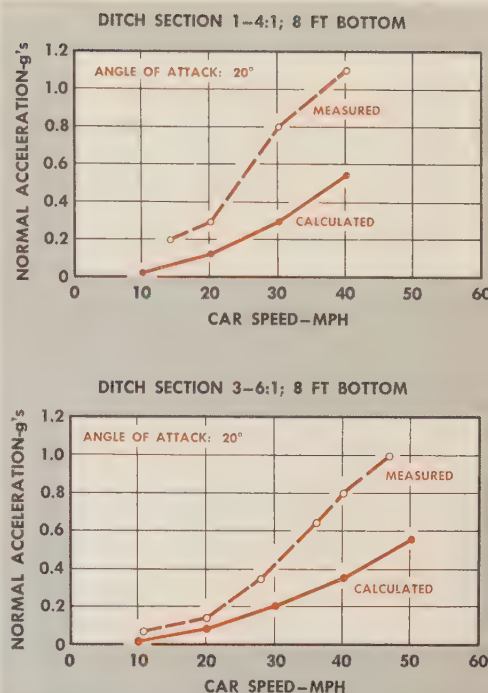


Fig. 6—These graphs compare the calculated values of acceleration with the measured values obtained during the ditch tests on section 1 (top) and section 3 (bottom). At the relatively mild conditions obtained at 10 mph, there is reasonably close agreement between the measured and calculated values on both graphs, but the difference increases rapidly as the car's speed, and consequently, the severity of the test increases. This is especially true of the results on ditch section 1 where the slope is 4 to 1. The measured severity of tests was greater here than on ditch section 3 tests and the speed was limited to approximately 40 mph on section 1 tests rather than the 50 mph limit used on section 3 tests.

is the length of the vertical curve between the side slopes and the ditch bottom (Fig. 7). Obviously, the radius of curvature is the controlling feature. For design and construction purposes, however, it is easier to use a circular vertical curve and employ criteria based on vertical curve length.

This study showed that the vertical curve should not be neglected in the design, construction, and maintenance of a highway (Fig. 8).

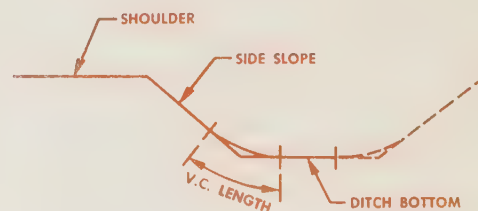


Fig. 7—This schematic drawing illustrates the elements which must be considered in ditch design. The most important element is the length of the vertical curve (V. C. length).

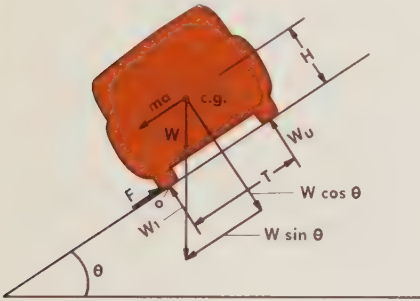
The conclusions of the investigation of ditch shapes indicated that ditch sections should be shallow and wide. Highways designed for practical speeds above 65 mph should have vertical curves at least 6.5 ft long on each side of the ditch bottom. Such sections give computed values of normal acceleration of 0.5 g at a 15° angle of attack.

Tests Show Importance of Slopes to Car Stability

Since there are little data upon which to base design criteria for the value of side slopes on fill sections, the Proving Ground also conducted tests on roadside slopes.

It is obvious that some slopes are too steep, or the transition from the side slope to the natural grade is too abrupt. Experience also shows that on a relatively flat gentle slope a car slides rather than overturns.

The force and moment relations on a car sliding down a side slope are shown in the following diagram:



where

W = weight of the car (lb)

T = car tread (in.)

H = center-of-gravity height (in.)

Θ = angle of roadside slope

F = sum of the gravitational component and ground reaction or impact reaction against an obstacle at the point where the weight on the upper wheel, W_u , approaches zero.

The equilibrium of force components parallel to the slope of the plane is

$$\Sigma F_x = F - (ma + W \sin \Theta) = 0. \quad (1)$$

The equilibrium of normal force components is

$$\Sigma F_y = W_1 - W \cos \Theta. \quad (2)$$

And, the equilibrium of moments is

$$\Sigma M_o = \frac{T}{2} W \cos \Theta - H (ma + W \sin \Theta) = 0. \quad (3)$$

Therefore, from equation (1),

$$F = ma + W \sin \Theta. \quad (4)$$

And, from equations (4) and (3),

$$\frac{T}{2} W \cos \Theta - HF = 0, \quad (5)$$

$$F = \frac{T}{2H} W \cos \Theta. \quad (6)$$

Where

$\Theta = 0$, and

f = coefficient of friction or coefficient of ground reaction,

$$f = \frac{F}{W} = \frac{T}{2H}. \quad (7)$$

Thus, on a level road the coefficient of ground reaction which will balance the car about the reacting wheel is equal to the ratio $T/2H$, where T = tread width and H = center-of-gravity height. This ratio is referred to as the *stability factor* of a vehicle.

Equation (6) shows that the ground reaction force necessary to overturn a car sliding down a slope is proportional to the cosine of the angle of inclination of the slope. Consequently, the reaction force against the wheels required to overturn the car decreases as the angle of inclination of the slope increases.

It should be noted that the ratio of the horizontal and normal forces F/W in Equation (7) is analogous to a coefficient of friction; it is convenient to think of this as a coefficient of ground reaction required to give this equilibrium of overturning moments. It should be noted also that the value of this reaction is dependent upon the tread width and the center-of-gravity height as expressed in Equation (7). On a level road, for example, a car will overturn when the coefficient of friction exceeds the ratio of the tread and twice the center-of-gravity height. On a roadside slope, it is more appropriate to regard F/W as a coefficient of ground reaction.

The value of the deceleration which must be provided by the friction or ground reaction of the side slope to overturn the vehicle is determined from the preceding relations.

Solution for the deceleration, a , gives

$$ma = \frac{T}{2H} W \cos \Theta - W \sin \Theta \quad (8)$$

$$\frac{Wa}{g} = \frac{T}{2H} W \cos \Theta - W \sin \Theta \quad (9)$$

$$\frac{a}{g} = \frac{T}{2H} \cos \Theta - \sin \Theta \quad (10)$$

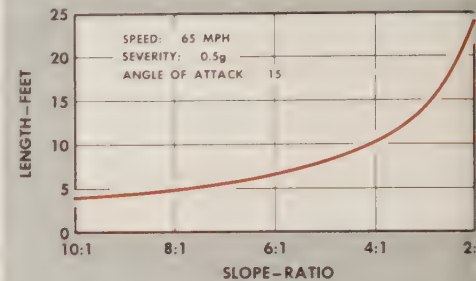
where

$\frac{a}{g}$ = the deceleration in gravity units or "g". It is in the same units and magnitude as f in Equation (7).

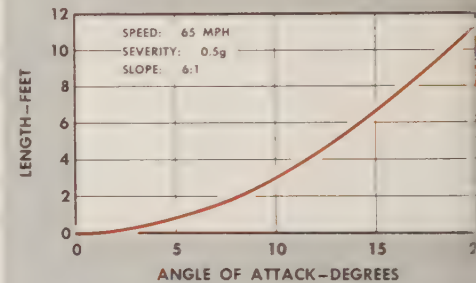
Using these relationships a curve can be plotted to show the effect of roadside slope on the deceleration required to overturn a car (Fig. 9).

As calculated approximately for static conditions, current automobiles have an average stability factor of about 1.4 with some small variations related to different design approaches (Fig. 10).

The significance of the stability factor $T/2H$ is that it is equal to the coefficient



a



b



c

Fig. 8—These graphs were prepared to show the relationship between the variables of angle of attack, ditch slope, length of the vertical curve, and severity of impact. All three graphs assume a car speed of 65 mph. Graph (a) shows that there is a rapid increase in the required length of the vertical curve as the ditch slope increases. Graph (b) illustrates that as the angle of attack increases, the length of the vertical curve must increase. Finally, graph (c) shows the decrease in the severity of impact as the length of the vertical curve is increased.

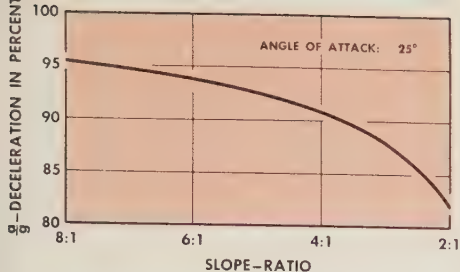


Fig. 9—This graph shows the effect of the roadside slope on the overturning or tripping deceleration of a car. It illustrates, for example, that the deceleration provided by the ground reaction necessary to overturn a car on a level road is reduced by about 6 per cent on a slope of 6 to 1 from that required on a level road; by about 9 per cent on a 4 to 1 slope; and by about 18 per cent on a 2 to 1 slope.

of friction or coefficient of ground reaction of the surface on which the car will overturn when it is sliding sideways. The units of stability factor are the same as those of coefficient of friction.

Because of the importance of the coefficient of ground reaction in the problem of roadside safety, some measurements were made by dragging a car sideways on several types of roadside surface.

While it was not possible with this series of tests to observe values of ground reaction at practical road speeds, oscillograms made in the range from 0 to 12 mph suggest that there is no important variation with speed nor, surprisingly enough, between wet and dry sod (Fig. 11). Oscillograms on both bituminous and Portland cement concrete showed the typical reduction in coefficient of friction with increase of speed but neither the dry nor wet sod tests suggested this type of change.

The maximum effective values of coefficient of ground reaction on a side slope with firm, dry sod will occur when there are irregularities in the surface such as bumps, ruts, stumps, and stones. These irregularities cause high values of impact resistance which may overturn the car. Another hazard is ground so soft that the wheels dig in and develop a large shear force against the edge of the groove in the ground.

The importance of the roadside slope in reducing the overturning deceleration level is of first order of significance (Fig. 9). The value of the slope also has secondary effects since the steeper the slope, the longer the car maintains its velocity and the greater the possibility that it will strike some surface irregularity which will overturn it. Furthermore, as the slope becomes steeper, the weight transfer from the upper to the lower wheels becomes

greater, and the indentation into the ground increases; this, in turn, usually increases the shear forces.

It appears, therefore, that slopes should be as flat as possible, certainly no steeper than 6 to 1 and preferably flatter. Slopes should be smooth and firm, and provide the lowest possible reaction against a car sliding sideways down them. Slopes should be free from obstacles such as stumps, firmly embedded stones, and erosion channels.

Design Applied to Proving Ground Road

The relation of roadside obstacles to off-the-road accidents was part of the

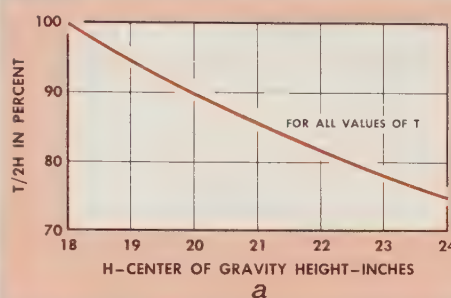
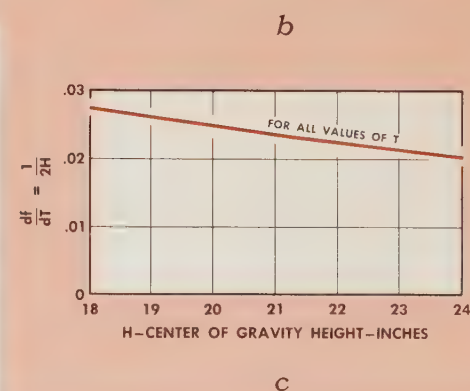
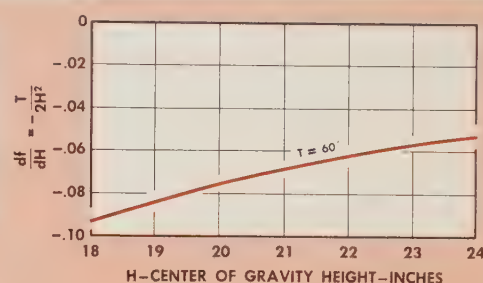


Fig. 10—The effect on the stability factor $T/2H$ of a variation in the tread width, T , and the center-of-gravity height, H , is shown on graph (a) for all treads in a practical range and in a range of center-of-gravity height from 18 in. to 24 in. The effect of lowering the height of the center of gravity is more important to this variation than the changing of the tread. Graph (b) shows the rate of change of f with respect to T . The derivative of this function with respect to T , $df/dT = \frac{1}{2}H$, is independent of T , indicating that f decreases as the reciprocal of H for all values of T . Graph (c) shows the rate of change of f with respect to H . In this case, the derivative of f with respect to H is inversely proportional to the square of H , so that the contribution of H to the stability index varies as the negative reciprocal of H^2 .

Proving Ground investigation; however a detailed discussion of this work is not presented in this paper. The bibliography lists additional papers which discuss this fully. The principal conclusion of these obstacle studies was that trees and signs within 100 ft of the highway should be removed for the ideal safety condition for normal highway speed, with proportionate reduction where speeds are restricted. The advantages offered by careful slope and ditch design include the ample room that is provided for the driver to maneuver without striking obstacles.

Where sign posts or lighting poles must be installed, improved designs were suggested. For example, the familiar traffic control signs are mounted at a standard height of 42 in. In a typical collision with

a traffic sign, the inertia of the sign causes the mounting bolts to rip loose and the sign starts to fall. At any appreciable speed, the car runs into it before it drops to the ground; on a test at 40 mph, for example, the 25-lb sign pierced the windshield partially and left a shower of glass in the front seat. At higher speeds, the sign would come through the windshield. With a sign mounted at a height of 60 in. or more, a car on a test at 40 mph passed under it harmlessly before the sign dropped far enough to strike the car (Fig. 12). Traffic signs on the Proving Ground roads have been changed to a height of 66 in.



Changes in the supporting structure of roadside lighting poles also can reduce the dangers from vehicle impact. Conventionally, light poles are made of cast steel and are erected on formidable concrete bases so that sufficient resistance to

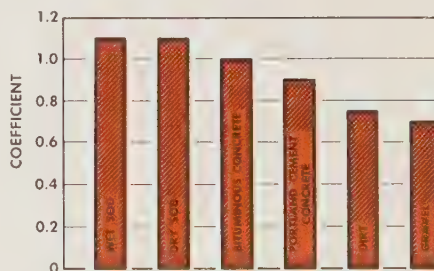


Fig. 11—This is a summary of the average values of lateral coefficient of friction or coefficient of ground reaction obtained from the tests.



Fig. 12—Proving Ground investigations of vehicles striking roadside obstacles included full-scale tests of signs, lighting poles, and ends of guardrails. The top left illustration (a motion picture frame) shows a remotely controlled vehicle hitting a sign (at 40 mph) that was installed at an experimental mounting height of 60 in. The impact with the mounting post tore the sign loose and the car passed harmlessly beneath before the sign fell far enough to be struck. On a similar test with a sign at the standard mounting height of 42 in., the car ran into the sign and the sign pierced the windshield. At higher speeds, the 25-lb sign would have gone completely through the windshield and the occupants would have run into it. The top right illustration (a motion picture frame) shows a remotely controlled vehicle just after striking a lighting pole of experimental design. This pole was constructed of light tubular material in a tripod arrangement with shear mountings at the base. With the resistance to impact of this tripod pole reduced because light tubular material was used and because the resistance was distributed on three legs, a vehicle striking the pole collapses the base with negligible impact and the car passes harmlessly beneath before the upper part of the pole has time to fall on it. Conventional poles are made of single rather than tripod structure and they are usually mounted on a concrete foundation. This heavy, stiff pole and the concrete foundation, particularly, present serious obstacles. The bottom illustration shows an experimental installation of a guard rail end buried in the ground on a ditch back slope. This installation eliminates the unprotected stiff beam end which can stop the car very abruptly if it is struck with a solid portion of the car such as the engine block, or it may impale the car and occupants if it strikes sheet metal or lighter car structure on either side of the block.

high winds is developed. These substantial objects immediately adjacent to the roadside present a lethal hazard when struck by a vehicle. As an improvement, the Proving Ground designed and constructed an experimental light pole using a tripod structure of light tubular material with shear mounts flush with the ground surface. On full-scale impact tests at 40 mph, a passenger car struck this pole and passed beneath it with only

superficial damage to the vehicle (Fig. 12).

There are many circumstances in which obstacles cannot be eliminated entirely and in which the terrain does not allow the ideal slope and ditch. In these cases, a guardrail must be used to protect against the more serious obstacles. How-



Fig. 13—The Proving Ground R & H Loop is an example of road construction using roadside safety concepts. It has broad, gentle slopes, and contains no obstacles within 100 ft of the pavement.

ever, the standard end construction of the guardrail also presents a lethal obstacle. More study of this problem is necessary. Some recent Proving Ground experiments show that the hazard of a vehicle striking the end of the guardrail can be eliminated by sloping the rail gradually into the ground, or by extending the rail across a ditch where the end can be buried in the ground (Fig. 12).

Summary

The suggestions derived from the Proving Ground experiments are being applied to the roads now comprising its highway system. The best example of the application of these design concepts is a test road known as the R & H Loop,

built in 1958 (Fig. 13). Although the road was constructed on favorable terrain, part of the area was heavily wooded and drainage requirements were unusually severe. The road today contains no obstacles within 100 ft of the pavement, the slopes are smooth and gradual, and the ditch bottoms are wide and gently rounded.

This work with off-the-road accidents indicates that there are various ways of approaching the problem of improving highway safety. Conducting driver education programs as well as perfecting traffic control and highway design help to prevent accidents on the road. The frequency and seriousness of off-the-road accidents can be reduced significantly by improving the roadside design.

Bibliography

Related literature in this field includes the following:

LUNDSTROM, L. C. and SKEELS, P. C., "Full-Scale Appraisals of Guardrail Installations by Car Impact Tests," *Proceedings of the Highway Research Board*, Vol. 38 (1959).

LUNDSTROM, L. C., "Safety Aspects of Vehicle-Road Relationships," Paper 66B, Society of Automotive Engineers, Inc., Summer Meeting (1958).

BEATON, J. L., and FIELD, R. N., "Dynamic Full-Scale Tests of Median Barriers," *Highway Research Board Bulletin 266—Pavement Edge Markings, Shoulders, and Medians*, 1960.

STONEX, K. A., "Roadside Design for Safety," *Proceedings of the Highway Research Board*, Vol. 39 (1960).

CICHOWSKI, W. G., SKEELS, P. C., and HAWKINS, W. R., "Guardrail Installations—Appraisal by Proving Ground Car Impact and Laboratory Tests," Presented at the 40th Annual Meeting, Highway Research Board, (1961).

Some Rules for Determining Inventorship

By HUGH L. FISHER

Patent Section

Detroit Office

THE United States Patent Laws provide that only *the inventor* may obtain a patent. These laws also require that this inventor be identified when the patent application is filed, even if the patent rights are assigned to a company or another person. In fact, the inventor must, if living and legally competent at the time the application is filed, take an oath that "he verily believes himself to be the . . . inventor . . ." Therefore, the determination of inventorship is just as important to patent rights as the invention itself, for a patent is invalid unless the true inventor is named.

The question of inventorship between employees of the same company is a matter to be determined within the company and is the subject matter of this article. If the alleged rights to the invention are hostile, for example, as between rival inventors, the U. S. Patent Office in an interference proceeding or the courts will determine the inventor. The wrong determination by the company, even if discovered promptly after the patent application is filed, will at least jeopardize patent rights and may cause a complete loss in many circumstances. Where a patent application is filed or a patent is granted with the wrong inventorship, it cannot be corrected by substitution of the true sole inventor for the supposed sole inventor or by substitution of the true joint inventors for the supposed joint inventors where none of the originally named inventors is a true inventor. Instead, the error can be corrected only by filing a new patent application with the correct inventorship and abandonment of the earlier erroneously filed application. Such correction necessarily results in a later patent application date and prejudices one's right to a patent in case a rival inventor also is seeking a patent. The correction is not permitted at all, and the patent rights are completely lost, if the invention has been on sale, in public use, or described in a printed publication more than a year before the new application is filed. On the other hand, if a

patent application is filed with mistaken inventorship but at least one true inventor is named as a joint inventor with one or more supposed inventors, the error can be corrected at any time by deleting the supposed inventors and leaving the true inventor as the sole inventor, if that is the case, or by substituting true joint inventors for the supposed inventors. In both cases, it is assumed that the mistake in inventorship was made without fraudulent or deceptive intent and action is taken promptly after discovery of the mistake.

The incorrect determination of inventorship can be very expensive especially where a company makes a substantial investment in the research and development of a new product. The loss of patent rights gives a competitor a distinct market advantage, for the competitor cannot only legally manufacture the product but can also sell it at a lower cost since the expense of research and development would not be a cost determining factor. Therefore, some of the fundamental principles involved in the problem of deciding who is the inventor will be discussed and applied to the more common fact situations that occur with either a joint or a sole invention. Of course, in each example, the statutory requirements for invention, namely that the invention must be new, useful, and unobvious, are presumed to have been met and that invention does exist.

Sole Invention

Sole Inventor Working Alone

Undoubtedly, the easiest situation is that taking place when one person conceives an idea and does all of the acts required by the law to complete the invention either by an actual or a constructive reduction to practice. In the case of an actual reduction to practice, the inventor himself would build and test the invention, whereas a constructive reduction to practice would only require that a patent application be filed. No problem is presented since there are no other parties involved in either case.

Sole Inventor Assisted by Others

In developing a new concept such as a new organization of known parts, an inventor may always avail himself of the mechanical and technical skills of others, either directly by discussion with them or indirectly through books and publications. Also, an inventor need not personally reduce his idea to practice but may have others assisting him, such as designers and mechanics, in working out design details and actually building and testing the invention. Neither instance of assistance will negate the establishment of a sole invention.

Joint Inventorship

Every invention can be said to have originated because of a problem, and through the exercise of inventive facilities by one or more parties a solution to the problem has been produced. Where several persons are involved in the solution to the problem, there may be joint inventorship among those who communicated with each other and contributed something to the unitary result.

No matter what the invention involves, for example, an apparatus, each of the parties under consideration as possible inventors must have contributed to the combination of elements thought to be the invention. In evaluating the contributions, those suggesting the desired results or those merely identifying the problem cannot be considered as inventors since they clearly have not contributed to the solution. Also, the amount of contribution or whether an apparatus element is broadly old, that is, the quality and quantity of assistance offered by each member under consideration, is immaterial. It merely must be established that the parties worked in concert and that their respective donations contributed to the unitary result. With this background, the sole inventor and his relationship to other parties can be re-examined as well as some of the other more complicated situations that frequently arise.

Sole Conception-Joint Invention

If the party conceiving at least the gist of an invention is subsequently joined by another party who assists in completing the invention and through their joint efforts, each making mutual contributions to the final inventive result, an operative invention is produced, they can become joint inventors.

An analogous situation arises when one party has conceived an idea and has actually made a design incorporating the concept, but it proved to be impractical and therefore unsatisfactory. If the one who conceived the idea thereafter consulted another and if a patentable improvement over the earlier conception was developed from their discussions of the problem, there has been the requirement of communication and mutuality so that joint invention does exist.

Sole Conception by One-Invention by Another

On the other hand, if there is no discussion or cooperation between the parties in the two foregoing examples and the invention is made operative, independently by the conceiving party, the one making the invention operative becomes the sole inventor. As an example, it may be that an inoperative model is observed and studied by one other than the conceiver and that independently of the conceiver the model is made to work. Since there was no communication between the parties, and it was only the party who made the model operate properly who completed the invention, he becomes the sole inventor.

Joint Conception-Joint Invention

Group research often produces even more complex factual situations. For instance, suppose that one of a group suggests a functional change in an existing structure, but there is nothing available to serve the function. If a suitable element is provided through the joint efforts of all of the group, they can be joint inventors.

Often, it may be discovered that it is virtually impossible to ascertain as between two or more parties who actually suggested one of the apparatus elements because the suggestion was developed in joint discussion. These scrambled contributions sometimes cannot be separated, and hence, such situations are sometimes regarded as joint inventions since the cooperative efforts of the parties still contributed to a unitary result.

Joint Conception-Sole Invention

However, if the joint efforts of the group produced a conception that was insufficient to enable another to perform the mere mechanical function of embodying the conception into an operative structure, there is still an incomplete invention. If subsequently one of the group works on the problem and completes the invention independently of the others, the one working alone may be considered the sole inventor.

Joint Conception-Joint Inventors Assisted by Others

Going one step further with the group discussion problem, it may be that the

group proposes a combination of elements, but one of the elements is suggested only as a means for accomplishing a certain function in the combination. If the means are readily available and do not require anything more than mere mechanical skill, the invention can be considered complete and the members of the group are joint inventors. Thus, if a mechanic not a part of the original group adapts a motor for accomplishing the means and in so doing does nothing more than would be expected of a skilled mechanic, he is not a joint inventor.

Conclusion

As has been suggested, the determination of inventorship requires first that the extent of the invention be known. In many instances, what is believed to be the invention at the time the patent application is filed may subsequently change during proceedings before the U. S. Patent Office because additional prior art is brought to the attention of the patent attorney. Whenever there is a change in the boundaries of what was believed to be the invention, the inventorship will have to be re-evaluated. Consequently, cooperation between the inventors and the patent attorney at the outset can aid in establishing these general boundaries far more accurately. It is particularly helpful to the patent attorney during the initial investigation to have available all the information about past work so that the inventorship problem can be confined to a more specific area.

Notes About Inventions and Inventors

The following is a general listing of patents granted in the names of General Motors employees during the period January 1, 1961 through March 31, 1961.

AC Spark Plug Division Flint, Michigan

• **Robert L. Carter**, (*B.S.E.E., University of Michigan, 1951*) project engineer, inventor in patent 2,968,248 for a magnetic drive impeller pump.

• **Earl M. Brohl**, (*B.S.E.E., George Washington University, 1929*) senior project engineer, inventor in patent 2,968,254 for a snap action diaphragm type liquid pump.

• **Harold H. Greenley**, (*Oshawa Collegiate and Technical Institute*) project engineer, and **Lucian B. Smith**, (*B.E.E., The Ohio State University, 1923*) executive engineer, inventors in patent 2,968,764 for electromagnetic indicators.

• **Karl Schwartzwalder**, (*B.Cer.E., 1930, and M.S., 1931, The Ohio State University*) director of research, and **Neil F. Meredith**, no longer with GM, inventors in patent 2,969,582 for a spark plug and process for making same.

• **Edwin F. Katz**, (*M.S.M.E., The Ohio State University, and B.S.M.E., University of Wisconsin*) manager, Reliability-Inertial Components, Milwaukee plant, inventor in patent 2,971,407 for a precision gear train for servo control mechanism.

Contributed by
Patent Section
Detroit Office

• **Harry M. Davis**, (*B.S.E.E., Purdue University, 1943*) administrative assistant, and **Reino O. Karell**, (*B.S.E.E., Milwaukee School of Engineering, 1951*) director, Titan Engineering Program, inventors in patent 2,971,596 for a vehicle speed control system.

• **Joseph Zubaty**, (*M.S.M.E., University of Prague, 1918*) staff engineer—special assignment, inventor in patent 2,974,601 for free piston fluid pumps.

• **Fremont T. Ogawa**, (*B.S.M.E., University of Idaho, 1936*) senior research engineer, and **Arthur E. Brown**, no longer with GM, inventors in patent 2,974,641 for a hydraulic differentiator.

• **Ralph H. Mitchel**, (*B.S.E.E., University of Michigan, 1929*) senior project engineer, and **Raymond E. Schwyn**, (*B.S. and M.S., Michigan State University*) inventors in patent 2,975,339 for a magnetic alloy.

• **Wilfred A. Bychinsky**, (*B.S.E.E., 1930; M.S.E., 1931; and Ph.D., 1933, University of Michigan*) chief engineer, automotive products, inventor in patent 2,977,498 for a spark plug.

*Allison Division
Indianapolis, Indiana*

• **John W. Rhodes**, (*B.S.Chem.E., Purdue University, 1921*) senior designer, inventor in patent 2,955,412 for a gas turbine nozzle control.

• **Robert L. Allen**, (*B.S.M.E., University of Illinois, 1944*) senior project engineer; **Joseph P. Miller**, (*Purdue University and Cornell University*) section chief, mechanical design; and **Harris C. True**, no longer with GM, inventors in patent 2,955,800 for a turbomachine stator assembly.

• **Oren F. Flaugh**, (*B.S.M.E., Tri-State College, 1931*) designer; **Richard A. Hirsch**, (*University of Dayton and Sinclair College*) project engineer; and **James R. Mansfield**, no longer with GM, inventors in patent 2,957,528 for a propeller mechanical low pitch stop.

• **Calvin C. Covert**, (*B.S.M.E., University of Cincinnati, 1950*) senior project engineer, and **Clifford B. Wright**, (*A.B., Wittenberg College, 1938*) assistant chief

engineer, aircraft propellers, inventors in patent 2,958,382 for a locking means for a pitch changing motor.

• **Frank G. Leland**, (*James Millikan University*) senior designer, inventor in patent 2,960,359 for a snap ring locking device.

• **Robert B. Koschmann**, (*B.S.M.E., Purdue University, 1941*) senior project engineer, and **Frederick R. Short**, (*B.S.M.E., Georgia Institute of Technology, 1939*) group head, fluid dynamics research, inventors in patent 2,962,809 for a method of making a compressor seal.

• **Dimitrius Gerdan**, (*B.S.M.E., and B.S.I.E., University of Michigan, 1932*) director of engineering, Aircraft Engineering Department, and **Stuart Wilder, Jr.**, no longer with GM, inventors in patent 2,963,269 for a composite turbine bucket.

• **Hamilton L. McCormick**, (*E.E. and M.E. degree, Johns Hopkins University, 1922, 1924*) special assignment, inventor in patent 2,963,271 for a turbine blade locking.

• **Harvey W. Welsh**, (*B.S.M.E., Wayne State University, 1942 and M.S.M.E., Columbia University, 1948*) chief, advanced projects, inventor in patent 2,963,272 for a rotor blade shrouding.

• **Robert P. Atkinson**, (*B.S.M.E., Purdue University, 1935 and B.S.M.E., Bradley University, 1940*) senior project engineer, and **Charles J. McDowall**, (*B.S.M.E., University of Florida, 1927*) technical assistant to the director of engineering, inventors in patent 2,964,132 for a lubrication system for a turbine engine.

• **Howard M. Geyer**, (*B.S.I.E., University of Alabama, 1940*) advanced systems engineer, inventor in patents 2,955,574 for a hydraulic actuator having cooled fluid circulation; 2,960,069 for a self-locking actuator; and 2,935,048 for an actuator assembly.

*Buick Motor Division
Flint, Michigan*

• **William C. Edgley**, (*General Motors Institute*) assistant chief draftsman, inventor in patent 2,968,195 for a control mechanism.

• **Shirrell C. Richey**, (*General Motors Institute, 1937*) assistant chief engineer, inventor in patent 2,974,916 for a flexible retainer.

*Central Foundry Division
Saginaw, Michigan*

• **George A. Zink**, (*B.S.M.E., Purdue University, 1929*) now executive engineer, GM Manufacturing Staff, and **Walter E. Taylor**, no longer with GM, inventors in patent 2,976,083 for an integrally cast vehicle wheel and brake drum with heat sink.

• **Merton L. Bartsch**, (*B.S.M.E., 1952, M.S.M.E., 1953, University of Minnesota*) senior engineer, and **William S. Hackett**, (*The Ohio State University*) research engineer, inventors in patent 2,976,589 for a method of manufacture.

*Chevrolet Motor Division
Warren, Michigan*

• **Donald H. Gill**, (*Detroit Institute of Technology*) fastener engineer, inventor in patent 2,970,287 for a fastener assembly.

• **Joseph F. Bertsch**, (*B.S.M.E., University of Cincinnati, 1948*) design engineer, inventor in patent 2,972,340 for a cooling and air supply system for internal combustion engines.

• **Robert P. Benzinger**, (*B.S.M.E., University of Wisconsin, 1948*) design engineer, inventor in patent 2,974,652 for venting systems for internal combustion engines.

• **Albert C. Hazard**, now with General Motors Overseas Operations, inventor in patent 2,974,986 for a bushing.

• **George H. Primeau**, (*Northern State Teachers College*) design engineer, inventor in patent 2,977,139 for a seal.

*Delco Appliance Division
Rochester, New York*

• **John G. Hart**, (*B.S.M.E., University of Rochester, 1949*) presently on educational leave of absence, inventor in patent 2,974,341 for a connector for windshield wiper blade.

• **Francis M. Ryck**, (B.S., *University of Rochester*, 1950) assistant supervisor, windshield wiper applications, and **Eugene M. Ziegler**, (*University of Rochester*) special development engineer, inventors in patent 2,975,548 for a windshield wiping system.

• **Wilbur L. Carlson**, superintendent, manufacturing facilities, inventor in patent 2,975,682 for a broaching method and apparatus therefor.

• **Peter R. Contant**, (*University of Rochester*) senior project engineer, inventor in patent 2,976,088 for an end play device for a dynamoelectric machine.

• **Francis M. Ryck***, inventor in patent 2,977,141 for a connector for windshield wiper blade.

Delco Moraine Division Dayton, Ohio

• **George E. Kellogg**, (B.S.M.E., *University of Nebraska*, 1948) senior project engineer, and **Robert H. Bauman**, supervisor, inventors in patents 2,968,155 and 2,969,046 for a power brake booster unit and a brake booster unit casting, respectively.

• **James O. Smiley**, (B.I.E., *General Motors Institute*, 1958) experimental engineer, inventor in patent 2,973,842 for a friction element.

• **Richard C. Rike**, (*General Motors Institute*) section engineer, inventor in patent 2,974,494 for a brake power booster.

• **Harold W. Schultz**, research engineer, and **Edward J. Vosler**, retired, inventors in patent 2,975,870 for a brake band.

• **Frank W. Brooks**, (B.S., *Case Institute of Technology*, 1935) senior project engineer, inventor in patent 2,976,957 for a brake structure.

Delco Products Division Dayton, Ohio

• **John F. Pribonic**, (B.S.M.E., *Princeton University*, 1947) staff engineer, inventor in patent 2,967,547 for a height control valve.

• **Ralph K. Shewmon**, (*General Motors Institute*, 1934) assistant chief engineer, electrical products, inventor in patent 2,975,528 for a prime mover for a clothes dryer.

• **John F. Pribonic***, and **Wayne A. Karlgaard**, (B.S.M.E., *North Dakota Agricultural College*, 1956) project engineer, inventors in patent 2,976,053 for a height control valve for a vehicle suspension.

Delco Radio Division Kokomo, Indiana

• **James H. Guyton**, (B.S.E.E., 1934, and M.S.E.E., 1935, *Washington University*) chief engineer—radio; **Richard L. Jenkins** (B.S.E.E., *Purdue University*, 1944) senior engineer; and **H. Rolland Buell**, (B.S.E.E., *Rose Polytechnic Institute*, 1941 and M.S.E.E., *University of Illinois*, 1947) project engineer, inventors in patent 2,970,212 for a transistorized low voltage receiver.

• **Bill J. Ford**, (B.S.E.E., *Purdue University*, 1943) senior project engineer; **James H. Guyton***; **Richard L. Jenkins***; and **Max J. Manahan**, (B.S.E.E., *Milwaukee School of Engineering*, 1922) staff engineer, inventors in patent 2,972,119 for a random sweep generator.

• **Carlton D. Barker**, (*Indiana University*) model shop group leader; **John G. Vent**, (*Tri-State College*) laboratory technician; and **William H. Lynch**, (B.S.Met.E., *Purdue University*, 1950) process development supervisor, inventors in patent 2,977,257 for a method and apparatus for fabricating junction transistors.

Delco-Remy Division Anderson, Indiana

• **Oscar H. Rhea**, senior engineer, inventor in patent 2,967,347 for a method of undercutting a commutator.

• **Charles W. King**, (B.S.E.E., *Purdue University*, 1949; M.S. in *Industrial Management*, *Massachusetts Institute of Tech-*

nology, 1959) executive engineer, and **William J. Rady**, (B.S.E.E., *University of California*, 1916) staff engineer, inventors in patent 2,967,990 for a control circuit.

• **Don G. Townsend**, (B.S.Met.E., *University of Illinois*, 1953) engineer-process, inventor in patents 2,971,042 and 2,971,043, both for a method of making storage batteries.

• **Brooks H. Short**, (B.S.E.E., 1931, and M.S.E.E., 1934, *Purdue University*) director of advanced engineering, and **Richard L. Sprague**, (B.S.E.E., *Purdue University*, 1953) senior research engineer, inventors in patent 2,977,506 for an electronic ignition system.

• **Brooks H. Short***, inventor in patent 2,977,507 for an ignition system.

Detroit Diesel Engine Division Detroit, Michigan

• **Charles H. Frick**, (B.S., *Iowa State College*, 1934) senior project engineer, inventor in patent 2,968,193 for a power plant governor control system.

• **Clyde W. Truxell**, (B.S., *University of Michigan*, 1927) general manager, and **Morris J. Duer**, (*The Ohio State University*) senior designer, Aeroproducts Operations, Allison Division, inventors in patent 2,976,863 for a hydraulic engine-starting device.

Detroit Transmission Division Ypsilanti, Michigan

• **Mayo M. Reichardt**, (B.M.E., 1944 and B.S.E.E., 1957, *Lawrence Institute of Technology*) supervisor, Machine Research and Development, inventor in patent 2,968,133 for an involute generating device and indexing mechanism therefor.

Electro-Motive Division La Grange, Illinois

• **William F. Holin**, (M.E., *Konstanz, Germany*) designer, inventor in patent 2,968,371 for a brake rigging stabilizer.

*Inventors' names marked with an asterisk have biographical listings noted previously in this issue's Notes About Inventions and Inventors.

*GM Engineering Staff
Warren, Michigan*

• **Lloyd M. Keighley**, patent attorney, Patent Section, Dayton Office, inventor in patent 2,967,409 for an ice harvesting arrangement.

• **Stanley H. Mick**, (B.M.E., *General Motors Institute*, 1955) project engineer, inventor in patent 2,968,473 for a pressurized fuel injection system.

• **Gilbert K. Hause**, engineer in charge, Transmission Development Group, inventor in patent 2,974,768 for variable speed fan drives.

*Euclid Division
Hudson, Ohio*

• **John A. Walko**, (B.S.M.E., *The Ohio State University*, 1951) senior product engineer, inventor in patent 2,968,189 for power steering having auxiliary steering control.

• **Ralph J. Bernotas**, (B.S.M.E., and M.S.M.E., *Case Institute of Technology*) senior product engineer, inventor in patent 2,974,430 for steerable material handling device.

*Fisher Body Division
Warren, Michigan*

• **George H. Howell**, (B.S.E., *St. Lawrence University*, 1930) senior project engineer, inventor in patent 2,968,064 for a clamping frame for vacuum forming parts.

• **Ernest V. Harper**, (B.S.E., *Northwestern University*, 1946 and *Marquette University*) production engineer, inventor in patent 2,968,713 for a weld assembly.

• **James D. Leslie**, (B.M.E., *University of Detroit*, 1939) engineer in charge, Mechanical Department, and **Alfred B. Sauer**, (B.S.E., *University of Michigan*, 1952) development engineer, inventors in patent 2,969,976 for a pivoted window regulator.

*Frigidaire Division
Dayton, Ohio*

• **Kenneth O. Sisson**, (B.S.M.E., *South Dakota State College*, 1936) senior project engineer, inventor in patents 2,967,546 and 2,973,637 for a separate wash and rinse temperature selector and a sediment collecting arrangement, respectively.

• **Richard S. Gaugler**, (B.S.Ch.E., *Purdue University*, 1922) supervisor of major product line, inventor in patents 2,969,515 and 2,971,546 for a domestic appliance and a method of filling a hollow ballast ring with demagnetized material.

• **Marshall C. Harrold**, (B.S.M.E., *Purdue University*, 1931) senior project engineer, inventor in patent 2,969,663 for an automatic sequential operation type clothes washing machine.

• **Albert J. Kuhn**, (B.S.E.E., *University of Dayton*, 1930) senior project engineer, and **David D. Rector**, no longer with GM, inventors in patent 2,969,959 for a refrigerating apparatus.

• **John R. Johnston**, (B.S.E.E., *Purdue University*, 1934) senior engineer, inventor in patent 2,970,463 for a clothes washing machine having a dispensing device.

• **Thomas E. Davidson**, (B.E.E., *University of Dayton*, 1951) project engineer, inventor in patent 2,972,817 for laundry apparatus.

• **Orson V. Saunders**, supervisor, major products, inventor in patent 2,973,235 for a refrigerator cabinet, patent 2,975,619 for a refrigerator with meat storage receptacle, and patent 2,975,616 for a refrigerating apparatus.

• **James W. Jacobs**, (B.S.M.E., *University of Dayton*, 1954) manager, research and future products engineering, and **Robert L. Mercer**, (B.M.E., *University of Dayton*, 1936) senior project engineer, inventors in patent 2,973,769 for a detergent dispenser for a dishwasher.

These patent listings are informative only and are not intended to define the coverage which is determined by the claims of each one.

• **Robert L. Mercer***, and **Carel F. Abresch**, no longer with GM, inventors in patent 2,973,907 for a spray device.

• **Kenneth O. Sisson***, and **Daniel J. Barbulesco**, (B.S.M.E., *Stanford University*, 1949) project engineer, inventors in patent 2,974,542 for a multi speed transmission.

• **Byron L. Brucken**, (B.S., *University of Dayton*, 1956) senior project engineer, inventor in patent 2,974,832 for a liquid detergent dispenser for a washing apparatus.

• **James A. Wallace**, (*Purdue University and University of Cincinnati*) project engineer, and **Nevin D. Nolder, Sr.**, layout man, inventors in patent 2,975,013 for a refrigerator hinge.

• **John H. Heidorn**, (*General Motors Institute*, 1947) project engineer, inventor in patent 2,975,613 for a refrigerating apparatus with aspirator in a by-pass.

• **Robert M. Neff**, tool design and machine layout, inventor in patent 2,975,817 for corrugating machines.

• **Richard E. Gould**, (B.S.M.E., 1923, and M.S.M.E., 1927, *University of Illinois*) chief engineer, inventor in patent 2,976,577 for a process of making foam cored laminates.

• **Kenneth O. Sisson***, and **Charles K. Billings**, (B.S.M.E., *University of Illinois*, 1957) supervisor, major product line, inventors in patent 2,976,710 for an automatic clothes washing machine.

*GMC Truck and Coach Division
Pontiac, Michigan*

• **Hans O. Schjolin**, (B.S. degree, *Karlstad College*, Sweden, 1920, and *Polytechnical Institute, Mittweida, Germany*, 1923) staff engineer, and **Donald K. Isbell**, senior engineer, inventors in patent 2,968,368 for a fluid-cooled vehicle disc brake.

• **Luther N. Kern**, (*Lehigh University, Wayne State University*) senior project engineer, inventor in patent 2,968,372 for an internal bleeder for vehicle brake.

- **Robert L. Hauser**, (B.M.E., *General Motors Institute*, 1953) senior project engineer, inventor in patent 2,969,779 for an internal combustion engine crankshaft sealing means.

- **Donald K. Isbell***, inventor in patent 2,970,673 for a combination tool and fitting for bleeding a brake and adjusting a wheel bearing.

- **Hans O. Schjolin***, inventor in patent 2,976,965 for a hydraulic cooling system for a multiple disc brake.

*Guide Lamp Division
Anderson, Indiana*

- **Kenneth R. Skinner**, (B.S. in radio engineering, *Tri-State College*, 1955) project engineer, inventor in patent 2,968,688 for a rain sensor.

*Inland Manufacturing Division
Dayton, Ohio*

- **Max P. Baker**, (A.B., *Miami University*, 1922) project engineer, inventor in patent 2,970,853 for a resiliently mounted ball joint.

- **Arthur J. Frei**, section engineer, inventor in patent 2,971,346 for refrigeration.

- **Thomas O. Mathues**, (B.M.E., *General Motors Institute*, 1947) chief engineer, inventor in patent 2,972,789 for a sealing strip and method of manufacturing such strip.

- **Harold J. Reindl**, (B.Ch.E., *University of Dayton*, 1942) section head, Paints, Coatings, and Adhesives Laboratory, inventor in patents 2,975,755 and 2,975,757, both for an electrostatic paint spray apparatus, and patent 2,976,175 for a method and apparatus for coating electrostatically and mechanically.

- **Harold J. Reindl***, and **John T. Marvin**, (B.S.Chem.E., *Case Institute of Technology*, 1934, and *Western Reserve University and Franklin College*) patent attorney, GM Patent Section, Dayton Office, inventors in patent 2,975,756 for an electrostatic paint spray.

- **Raymond C. Davis**, (M.E., *Dayton Night College*, 1920) administrative engineer, inventor in patent 2,976,573 for a method of molding a steering wheel.

*Oldsmobile Division
Lansing, Michigan*

- **Kenneth E. Faiver**, (B.S.E.E., *Notre Dame University*, 1924 and Ph.D., *Rensselaer Polytechnic Institute*, 1927) senior project engineer, and **Andrew K. Watt**, (B.S.E.E., *University of Utah*, 1929) advance design engineer, inventors in patent 2,972,391 for a power throttle and vehicle speed control mechanism.

- **Harold L. Howard**, (*Michigan State University*) design engineer, inventor in patent 2,974,752 for a positive parking brake.

*GM Overseas Operations Division
New York, New York*

- **Kenneth E. Buckman**, manager, Design and Production Engineering, No. 2 plant, AC-Delco Division, Southampton, England, inventor in patent 2,968,361 for filters for gases.

*Packard Electric Division
Warren, Ohio*

- **Robert C. Woofter**, (*Fenn College*) chief, Wiring Assemblies Design and Development Section, and **Robert G. Van Wingerden**, (B.I.E., *General Motors Institute*, 1959) work standards engineer, inventors in patent 2,953,769 for a socket and terminal means for pin-type lamp bulb connection.

*Pontiac Motor Division
Pontiac, Michigan*

- **John Z. DeLorean**, (B.S.I.E., *Lawrence Institute of Technology*, 1948; M.S.A.E., *Chrysler Institute*, 1952; M.B.A., *University of Michigan*, 1957; and *Detroit College of Law*) assistant chief engineer in charge of advanced design and body, inventor in patents 2,968,197 and 2,968,358 for a transmission and a swing axle suspension for vehicle driving wheels, respectively.

- **Albert E. Roller**, (M.E., *College for Mechanical Engineers, Esslinger, Germany*, 1937) assistant advanced design engineer, inventor in patent 2,968,357 for an anti-squat swing axle suspension.

- **Dallas B. Avery, Sr.**, foreman, Master Mechanic Department, inventor in patent 2,968,375 for a machine rail steel plug.

- **Mark H. Frank**, (B.S.M.E., *Michigan State University*, 1927) motor engineer, inventor in patent 2,969,718 for a combustion chamber and method of forming combustion chamber cavities.

*GM Research Laboratories
Warren, Michigan*

- **Jule Brinn**, (M.S. in engineering mechanics, *Wayne State University*, 1958) research engineer, inventor in patent 2,968,299 for an ignition control.

- **Manuel Ben**, (B.S. in Chemistry, *University of Michigan*, 1939) supervisor, Electrochemistry Department; **Harry M. Bendler**, (Ph.D., *University of Michigan*, 1949) research associate; **Carl E. Bleil**, (Ph.D., *University of Oklahoma*, 1953) senior research physicist; **Theodore W. Hertzog**, now with GM Photographic; and **Mitchell A. LaBoda**, (B.S.Ch.E., *University of Detroit*, 1951) senior research engineer, inventors in patent 2,968,555 for the treatment of metal surfaces.

- **Floyd A. Wyczalek**, (B.S.M.E., *Worcester Polytechnic Institute*, 1946) now supervisor, Power Development Group, GM Engineering Staff, inventor in patent 2,969,780 for an engine cooling system.

- **Joseph L. Greene**, (B.A. in chemistry, *Wayne State University*, 1956) research chemist, and **James C. Holzwarth**, (B.S.M.E., 1945, and M.S.M.E., 1948, *Purdue University*) assistant head, Metallurgical Engineering Department, inventors in patent 2,970,065 for forming an aluminum-containing alloy protective layer on metals.

- **Emmett D. Conklin**, test supervisor, Engineering Development Department; **Eugene E. Flanigan**, (B.S.M.E., *Purdue University*, 1950) supervisor, vehicle applications group; **James M. Rickets**, (*Gen-*

eral Motors Institute, 1944) supervisor, engineering design, and William A. Turunen, (B.S.M.E., Michigan College of Mining and Technology, 1939, and M.S., Columbia University, 1946) head, Engineering Development Department, inventors in patent 2,972,230 for an automobile gas turbine.

- **Harold W. Ferchland**, senior engineer, inventor in patent 2,972,485 for a magnetic chuck.

- **John M. Farrell**, (Lawrence Institute of Technology) project engineer, and **Edward F. Weller, Jr.**, (B.S.E.E., University of Cincinnati, 1943) assistant head, Physics Department, inventors in patent 2,976,459 for a digital computer.

- **Raymond S. Amala**, (B.S.Met.E.; M.S. Met.E.; and B.S.Ch.E., Michigan College of Mining and Technology, 1942) supervisor, special molding, and **Royal E. Scroeder**, (University of Detroit) senior metallurgical technician, inventors in patent 2,976,588 for a method of manufacture and article resulting therefrom.

- **Richard M. Zeek**, (B.S.M.E., Agricultural and Mechanical College of Texas, 1953) senior research engineer, and **Eugene E. Flanigan***, inventors in patent 2,975,683 for a gas turbine fuel system.

- **Robert J. Bayer**, (B.M.E., University of Detroit, 1952) senior research engineer, inventor in patent 2,976,860 for a gas fuel injection system.

- **Robert R. Bockemuehl**, (B.S.E.E., University of Michigan, 1952) senior research engineer, inventor in patent 2,977,499 for an electronic drift compensator.

- **Norman W. Schubring**, (B.S.E.E., 1952 and M.S.E.E., 1959, Wayne State University) senior research engineer, and **Merle E. Fitch**, no longer with GM, inventors in patent 2,977,544 for a differentiating circuit.

Rochester Products Division Rochester, New York

- **Donald D. Stoltman**, (B.S.M.E., Rensselaer Polytechnic Institute, 1947, and M.S. in automotive engineering, Cornell University, 1948) senior project engineer, inventor in patent 2,968,476 for a throttle valve control mechanism.

- **Adolph F. Braun**, (B.S.M.E., University of South Dakota, 1928) chief engineer, inventor in patents 2,969,783 and 2,969,965 for a choke actuating mechanism and a fuel metering pin, respectively.

Saginaw Steering Gear Division Saginaw, Michigan

- **Elmer R. Wagner**, (B.S.M.E., University of Michigan, 1951) design engineer, inventor in patent 2,971,770 for a ball joint assembly.

- **Robert L. White**, (B.S.M.E., Purdue University, 1947) design engineer, inventor in patent 2,972,261 for a variable ratio steering gear.

GM Styling Staff Warren, Michigan

- **Harvey J. White**, (B.S.M.E., University of Southern California, 1944; Industrial Design, California Institute of Technology, 1948) chief designer, Frigidaire Studio, inventor in patents 2,955,006 and 2,960,848 for an egg storage means for refrigerators and refrigerating apparatus, respectively.

- **Edward P. Krajewski**, senior layout man, inventor in patent 2,955,648 for a pop-up arm rest.

- **John Himka**, (diploma in Aero.E., Academy of Aeronautics, 1941) chief engineer, Body Development Engineering, inventor in patent 2,955,871 for a flipper finger guard.

- **Hans O. Koplin**, (Diploma, Technical Institute—Art School, Berlin, Germany, 1926) senior project engineer, inventor in patent 2,956,837 for a seating arrangement for vehicle bodies.

- **Edward G. Podolan**, (Lawrence Institute of Technology) senior project engineer, and **Charles S. Stebbins**, (B.A., Michigan State University, 1941) creative designer, inventors in patent 2,959,447 for a rear compartment cover for convertible.

- **Julius Hezler, Jr.**, senior design engineer, inventor in patent 2,962,933 for a remotely controlled mirror.

- **Raymond M. Spencer**, supervisor, Interior Engineering, inventor in patent 2,965,156 for a seat adjusting mechanism.

- **John Himka***, inventor in patents 2,969,977 and 2,974,998 for a window regulator and an adjustable easy entrance seat for automobiles, respectively.

- **David R. Holls**, (B.A. in Industrial Design, Michigan State University, 1953) assistant chief designer, Chevrolet Studio, inventor in patent 2,970,290 for a front fender turn indicator lamp.

- **Robert B. Hicks**, (B.S. in Industrial Design, Pratt Institute, 1953) senior designer, and **Edwin O. Grahm**, (Industrial Design, Pratt Institute, 1939) chief designer, Advanced Product Design, inventors in patent 2,973,236 for refrigerator shelving.

- **Wesley F. Thull**, (B.S.M.E., University of Detroit, 1953) senior project engineer, inventor in patent 2,975,012 for refrigerating apparatus.

Ternstedt Division Detroit, Michigan

- **Barthold F. Meyer**, (B.S.M.E., Pratt Institute, 1939, and Johns Hopkins University) engineering group supervisor, Product Engineering Department, and **Nicholas Toruk**, (B.S.M.E., University of Detroit, 1951) senior project engineer, inventors in patent 2,968,703 for a circuit controller.

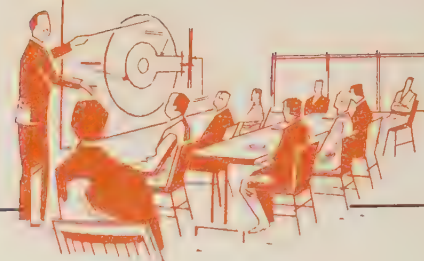
- **Alfonsas Velavicius**, (University of Kansas and University of Detroit) senior designer, inventor in patent 2,970,006 for a tail gate window regulator lock-out.

- **LaVerne B. Ragsdale**, (University of Detroit, Franklin College, and B.S.M.E., Lawrence Institute of Technology, 1939) divisional sales manager, inventor in patent 2,970,015 for a cage and bearing assembly for seat adjuster slide structures.

- **Eugene W. Hines**, (B.S.M.E., University of California, 1939) now with AC Spark Plug Division, inventor in patent 2,972,263 for a lock mechanism.

- **Arthur W. Hollar, Jr.**, (B.S.M.E., University of Michigan, 1941) senior designer, inventor in patent 2,947,023 for a door hinge, check, and hold-open.

Technical Presentations by GM Engineers and Scientists



Information about technical developments in General Motors is made available through several media, one of which is the technical presentation. Presentations, such as those listed below, include lectures to student engineering classes or societies, papers presented before professional groups, and talks before civic or governmental organizations. Requests for presentations by GM engineers and scientists before student groups may be sent to the Educational Relations Section, Public Relations Staff, General Motors Corporation, General Motors Technical Center, Warren, Michigan.

Automotive Engineering

G. W. Roberts, assistant experimental engineer, Pontiac Motor Division, before the Aparajitos, Waterford, Michigan, title: Ways and Means of Improving Engine Output.

Warren M. Wiese, senior research engineer, **Russell F. Stebar**, research engineer, and **Robert L. Everett**, research engineer, GM Research Laboratories, before the Saginaw Valley, Michigan, Oil Men's Club, title: Engine Rumble—A Barrier to Higher Compression Ratios?

Joseph Sherwood, general supervisor, engineering specifications, Buick-Oldsmobile-Pontiac Assembly Division, Kansas City plant, before the University of Kansas student chapter, American Society of Tool and Manufacturing Engineers, title: Automobile Assembly Operations.

Marshall D. McCuen, general supervisor, Allison Division, before the Indianapolis chapter, American Society of Mechanical Engineers, title: A Gas Turbine Engine for Ground Vehicle Propulsion.

Robert F. Caughill, assistant chief engineer, Harrison Radiator Division, before the A.S.M.E., Washington, D. C., title: Design Considerations and Operating Experience of Regenerators for Industrial Gas Turbines.

Frank W. Sinks, senior project engineer, Detroit Diesel Engine Division, before the American Trucking Associations, Baltimore, title: Diesel Engine Exhaust Odor Control.

J. M. Murphy, manager, compressor engineering, Frigidaire Division, before the Round Table Club and the Engineers Club, Dayton, title: Auto Air Conditioning.

John Tierney, divisional manager, process engineering, Brown-Lipe-Chapin Division, before the Kiwanis Club, Syracuse, New York, title: Effect of Salt on Corrosion of Automobiles.

Floyd Wyczalek, section engineer, GM Engineering Staff, before a S.A.E. national automobile week student activity meeting, Detroit, title: Piston Engines in the Space Age.

From AC Spark Plug Division: **Donald R. Thoreson**, field service engineer, before the Aircraft Spark Plug Seminar, Travis Air Force Base, California, title: Aircraft Spark Plugs; and **Matthew J. Rozboril**, product engineer, before the Electric Supply and Service Company, Brainerd, Minnesota, title: Spark Plugs for Outboard Engines.

Before various sections of the S.A.E.: **Bart Cotter**, chief engineer, body engineering activity, Fisher Body Division, before the mid-Michigan section, Frankenthum, title: Operation Corvair; and **C. G. Studaker**, section engineer, Buick Motor Division, before the Milwaukee section, title: The New Buick Aluminum Engine.

From Delco Products Division: **Henry K. Dexter**, supervisor, service publications, and **Forrest G. Brandt**, product manager, automotive products, before the Civitan Club, Dayton, titles: The Care, Home Life, and Feeding of Shock Absorbers, and Delco's New Superlift, respectively.

From Rochester Products Division: **Frank Sciabica**, senior project engineer, and **Richard Klotzbach**, junior service engineer, before the Corvette Club of Rochester, New York, titles: Fuel Injection, and Carburetion, respectively.

Pontiac Motor Division engineering personnel who made the presentation, The Pontiac Tempest—A Car Without a Counterpart, included: **John Z. DeLorean**,

assistant chief engineer, before a joint meeting of the St. Louis section, S.A.E., and the Engineers Club of St. Louis; **Robert H. Knickerbocker**, senior project engineer, before the University of Wisconsin student chapter, S.A.E.; **Edmund L. Windeler**, experimental engineer, before the Metropolitan New York section, S.A.E.; **G. W. Roberts**, assistant experimental engineer, before the Auto Enthusiasts International, Detroit; and **Stephen P. Malone**, assistant chassis engineer, before the Dayton section, S.A.E.

From Chevrolet Motor Division: **Zora Arkus-Duntov**, director, high performance vehicle design and development, before the Saginaw Valley Sports Car Club, Saginaw, Michigan, title: The Chevrolet Corvette; and **Robert L. Westervelt**, resident engineer, before the Birmingham, Alabama, section, A.S.M.E., title: Chevrolet's Engineering Laboratory.

S.A.E. National Automobile Week Meeting

The following GM personnel made presentations at the S.A.E. 1961 national automobile week meeting, Detroit, March 13-17.

From Buick Motor Division: **F. R. Daley**, staff engineer, and **R. J. Christensen**, engineer, title: Buick's Low-Profile Driveline; **L. M. Morrish**, staff engineer, and **R. R. Haist**, engineer, title: The Effect of Loaded Radial Runout on Tire Roughness and Shake; and **W. F. Williams**, assistant welding engineer, and **S. M. Spice**, engineer, title: Arc Welding Rear Axle Housings and Related Assemblies.

From the GM Manufacturing Staff: **Albert E. Katzer**, senior welding engineer, title: The Requirements of Arc Welding Processes by the Automotive Industry; **Irvin E. Poston**, senior project engineer, and **K. J. Mack**, project engi-

neer, title: The Glue Line—Why, How, and When: **Ronald A. Featherstone**, director of process engineering, title: Relationship of Manufacturing Development to Product Design; **Clayton J. Tribble**, executive engineer, member of panel discussing Challenge Facilities for Better Return on Assets; and **William A. Fletcher**, executive engineer, member of panel discussing High Energy Forming Processes.

David D. Campbell, assistant engineer in charge, mechanical design group, Fisher Body Division, title: Convenience in Motion—Power Operated Body Mechanisms.

Joseph B. Bidwell, head, Engineering Mechanics Department, GM Research Laboratories, title: Problems and Possibilities of Automatic Vehicle Control.

Donald P. Marquis, assistant chief engineer, Saginaw Steering Gear Division, title: Low Tunnels Mean High Angles.

James J. Gumbleton, project engineer, GM Engineering Staff, title: Piston Ring and Cylinder Wear Measurements Illustrate Potential and Limitations of the Radioactive Technique.

Bearings and Lubrication

Donald F. Hays, senior research engineer, GM Research Laboratories, before a joint meeting of the S.A.E. and the American Society for Metals, Muskegon, Michigan, title: Lubrication to Resist Wear.

F. E. Salb, senior project engineer, Allison Division, before the American Society of Lubrication Engineers, Minneapolis, title: Lubrication Characteristics of the Allison 501-D13 Engine.

Robert Guy, senior engineer, Detroit Transmission Division, before the A.S.L.E., Detroit, title: Consider the Maintenance Man.

GM personnel who made presentations before the national A.S.L.E. meeting in Philadelphia included: **Ward F. Diehl**, supervisor, hydraulics and lubrication, GM Manufacturing Staff, title: A Mechanical Problem in the Lubrication of High Speed Gears; and **T. W. Selby**, senior research chemist, GM Research Laboratories, title: Calculation of Engine Cranking Speed from Engine Oil Viscosity at Low Temperatures.

From New Departure Division: **Mark Goedecke**, supervisor, eastern area engineering, before engineering and plant

personnel, Aero Weapons Division, Raytheon Company, Andover, Massachusetts, title: New Departure Types, Mounting, and Lubrication; **R. E. Murteza**, contract supervisor, before the 46th Air Force—Industry Conference, Riverside, California, title: Improved Aircraft Bearing Reliability Through Analysis of Performance and Related Design Factors; **A. H. Kelso**, manager, instrument bearing development and contract, before the Knights of Columbus, Huron, Ohio, title: Missile Bearings; **C. R. Gillette**, manager, research chemistry, before the Cleveland section, A.S.L.E., title: Multi-purpose Lubricating-Cutting Oils; **Arthur F. Campbell**, aircraft project engineer, before engineers of the Pesco Products Division, Borg Warner Corporation, Cleveland, title: Aircraft Ball Bearing Applications; and **Robert B. Walker**, project engineer, before engineers of the Bodine Electric Company, Chicago, title: Effect of Ball Bearings on Electric Motor Sound.

Computers and Mathematics

Karl Usow, supervisor, problem analysis and programming, AC Spark Plug Division, before the Milwaukee chapter, A.S.M.E., title: Computer Applications in the Space Age.

E. J. Kovalcik, senior experimental engineer, Allison Division, before the Instrument Society of America, St. Louis, title: Design of a Central Data Acquisition System.

Bruce R. Polinghorne, assistant general supervisor, Detroit Diesel Engine Division, before the Lawrence Institute of Technology computer seminar, Detroit, title: Engineering Applications of Electronic Computers.

Richard A. Haertle, manager, scientific data processing, AC Spark Plug Division, before students of Milwaukee Lutheran High School, title: Mathematics as a Tool in Industry.

Allison Division engineers who made presentations before the Midwestern Simulation Council, Indianapolis, included: **R. O. Whitaker**, project engineer, title: Analog Techniques Employed in Trajectory Study, and **J. E. Westwick**, experimental engineer, title: Extended Use of a General Purpose Analog Computer for Missile Control System Development.

GM Research Laboratories personnel who made presentations before American Mathematical Society meetings included: **T. W. Ting**, senior research mathematician, Washington, D. C., title: On the Solution of $\Delta u - q(x)u = f(x,y)$ Over a Rectangular Domain; **C. W. de Boor**, research mathematician, Chicago, title: Bicubic Spline Interpolation; and **J. S. White**, senior research mathematician, Chicago, title: Two Rank Order Theorems.

Electrical Engineering

Leonard R. Hostetter, engineer, Buick-Oldsmobile-Pontiac Assembly Division, before the Plant Engineering and Maintenance Conference, Chicago, title: Keeping Ahead of Power System Problems.

From Delco Radio Division: **J. R. Atkinson**, senior project engineer, before the Automatic Train Operations Committee of Canada, Detroit, title: Hy-Com; **William C. Caldwell**, supervisor, field service, and **Lawrence E. Brown**, electrical engineer, before Valparaiso Technical College, Valparaiso, Indiana, title: Transistors; **Philip R. Powell**, service engineer, before personnel of Hanscom Air Force Base, Bedford, Massachusetts, title: Transistor Circuits and Troubleshooting; **Jack O. Beasley**, service engineer, before personnel of Tinker Air Force Base, Oklahoma, title: Transistor Fundamentals, Circuits, and Troubleshooting; and **E. R. Buehler**, technician, before the Kokomo, Indiana, Radio and TV Service Association, title: Radio and TV Interference Problems.

Guided Missiles and Space Technology

Howard A. Wilcox, director, research and engineering, Defense Systems Division, before the Detroit section, American Rocket Society, title: Sidewinder Guided Missile.

Before the S.A.E. national aeronautical meeting, New York City: **R. E. Henderson**, chief, applied physics research, Allison Division, title: A Solar Thermionic Satellite Power System; and **F. D. Wallace**, senior project engineer, Allison Division, title: A Test Facility Design for 250,000-Pound Thrust Nuclear Rocket Engines.

From Allison Division: **Tibor F. Nagay**, director of research, before the NATO-

AGARD meeting, Paris, France, title: Light Metal Tri-Propellants for Rocket Propulsion; **R. E. Henderson**, chief, applied physics research, before the Institute of Radio Engineers, Cincinnati, title: Micro-meteorite Damage on Solar Reflectors; **M. C. Hardin**, chief, propellants and combustion research section, and **A. I. Masters**, research engineer, before the western states section of the Combustion Institute, Newport Beach, California, title: The Use of Lithium as a Rocket Propellant; **R. B. McClure**, senior engineering scientist, before the I.S.A., St. Louis, title: An Experiment to Determine the Effect of Meteorites on Reflecting Surfaces; and **M. D. Parker**, senior project engineer, before the Purdue University student section, S.A.E., Lafayette, Indiana, title: Stirling Engine Development for Space Power.

From AC Spark Plug Division's Milwaukee plant: **B. P. Blasingame**, director of engineering, before the Industrial Club of the Employers' Association of Milwaukee, title: Space and Space Travel; **Robert G. Brown**, director of ACRD, before the De Vry Institute student chapter, Institute of Radio Engineers, Chicago, title: Inertial Guidance; **Charles Shupe**, head, field service maintenance department, before the Men's Club, First Evangelical United Brethren Church, Milwaukee, title: Inertial Guidance; **Oliver Luey**, supervisor, field service training, before the American Electroplaters' Society, Milwaukee, title: Basic Missile Guidance; **Gerald Haizlett**, instructor, field service training, before boy scouts and fathers, Milwaukee, title: Inertial Guidance; and **Anthony J. Italiano**, Mace program definition and control, before the Kenosha, Wisconsin, Manufacturers Association, title: Inertial Guidance. From AC-Flint: **Leonard E. A. Batz**, senior project engineer, before the Davison, Michigan, Masonic Lodge, title: The Gyroscope and Space Flight.

Highway and Traffic Engineering

From GM Proving Grounds: **Louis C. Lundstrom**, director, before the Georgia Highway Conference, Atlanta, title: Highway Activity at General Motors Proving Ground; **Kenneth A. Stonex**, assistant director, before the 47th annual Purdue University road school, Lafayette, Indiana, titles: Scientific Highway De-

sign for Safer Motoring, and Vehicle Characteristics and Their Influence on Highway Design; **Paul C. Skeels**, head, Experimental Engineering Department, before a Bethlehem Steel executive group, Bethlehem, Pennsylvania, title: Guard-rail Installations—Appraisal by Proving Ground Car Impact and Laboratory Tests; and **David C. Apps**, head, Noise and Vibration Laboratory, before the Public Health Service, Cincinnati, title: Vehicular Noise—The Industry-Wide Approach.

From GM Research Laboratories: **D. C. Gazis**, senior research scientist, before the Michigan State University seminar for science writers, Warren, Michigan, title: Remarks On the Theory of Traffic Flow.

Instrumentation

From GM Research Laboratories: **Albert F. Welch**, head, Electronics and Instrumentation Department, and **John L. Harned**, senior research engineer, before the Saginaw Valley chapter, A.S.M., Saginaw, Michigan, title: Metallurgical Research Using Modern Instrumentation; and **Paul K. Winter**, research associate, before the Metropolitan Detroit Science Club, title: Making Meaningful Measurements.

T. A. Prewitt, senior project engineer, Delco Radio Division, before the Maple Crest School science class, Kokomo, Indiana, title: Electronic Measurement of Reaction Time.

Manufacturing

Wallace E. Wilson, general manager, Rochester Products Division, before the Rochester Institute of Technology management seminar, title: Cost Reduction and Productivity Improvement.

M. H. Wilson, supervisor, manufacturing expense material control and budgets, Allison Division, before the Indianapolis chapter, American Institute of Industrial Engineers, title: Progressive Elements of Manufacturing Expense Control.

Donald J. McIntosh, supervisor, methods engineering, McKinnon Industries Limited, before the 16th annual management engineering conference, S.A.E.-A.S.M.E., New York City, title: Cost Reduction Through Methods Engineering Team.

Claude H. Leland, senior metallurgical

engineer, GM Manufacturing Staff, before the Indianapolis chapter, A.S.M., title: What Furnace Should Be Used for Special Heat Treating Jobs.

Donald F. Eary, faculty member, General Motors Institute, before the A.S.T.-M.E. seminar, Chicago, title: Die Design and Press Tooling.

From AC Spark Plug Division: **F. A. Cuthbertson**, director of production engineering, Milwaukee plant, before the A.S.T.M.E., Milwaukee, title: Team Engineering Concept to Production Engineering Management; **Glen R. Fitzgerald**, director of engineering and equipment sales, before the S.A.E., Detroit, title: Better Communications Between Product Engineering and Manufacturing; and **John R. Wilson, Jr.**, director of production engineering, Flint plant, before the 5th annual Purdue University manufacturing conference, title: Coordinating Research, Engineering, and Production Talents for the Development of Integrated Equipment.

Metallurgy

Warren Rushman, supervisor, metallurgical processing, Detroit Diesel Engine Division, before the Massillon, Ohio, chapter, A.S.M., title: Evaluation of Quenching Systems as a Guide in the Selection of Steel.

John A. Shandley, section head, Metallurgy Department, General Motors Institute, before the Junior Engineering Technical Society, Flint, Michigan, title: Structure and Properties of Metals and Alloys.

G. Max Haviland, senior engineer in charge, Trim and Hardware Styling Department, Fisher Body Division, before the annual meeting of the Society of Vacuum Coaters, Chicago, title: Vacuum Metalizing.

Robert A. Sprague, metallurgist, New Departure Division, before the Stevens Institute of Technology x-ray diffraction seminar, Hoboken, New Jersey, title: Procedures for Determining Retained Austenite.

From Allison Division: **R. H. Singleton**, supervisor, ceramic and cement development, before the Western Metals Congress, Los Angeles, title: The Fabrication of Tungsten Shapes by Plasma Arc Spray Techniques; **E. L. Bolin**, plant metallurgist, before the Indianapolis corrosion committee, title: Corrosion and the Gas Turbine Aircraft Engine; and

Dean Hanink, chief metallurgist, before the Chicago chapter, A.S.M., title: Metallurgy and Quality Control in the Manufacture of Thin Wall Rocket Motor Cases.

From Ternstedt Division: **William E. Lovell**, engineer in charge, process engineering, before the Cleveland branch, American Electroplaters' Society, title: Dual Chromium; and **Eldon H. Shotwell**, senior process engineer, before the Detroit branch, A.E.S., title: Dual Chromium.

From GM Research Laboratories: **R. F. Thomson**, head, Metallurgical Engineering Department, before the A.S.M., Buffalo, title: What Metallurgical Engineering Can Do for Management; **W. D. McMaster**, assistant head, Chemistry Department, before the first international congress on metallic corrosion, London, England, title: The Accelerated Corrosion Testing of Metals; **W. L. Grube**, assistant head, Physics Department, and **S. R. Rouze**, senior research physicist, before the metallurgy department seminar, University of Illinois, title: The Application of Thermionic Emission Microscopy to the Study of Metals at High Temperatures; **T. J. Hughel**, supervisor, Metallurgical Engineering Department, before the Michigan State University seminar for science writers, Warren, Michigan, title: Beryllium—A Space Age Metal; **D. J. Harvey**, senior research metallurgist, before the A.S.M., Jackson, Michigan, title: Principles Underlying the Selection of Steels; **L. C. Rowe**, senior research chemist, and **M. S. Walker**, junior research chemist, before the National Association of Corrosion Engineers, Buffalo, title: The Effect of Mineral Impurities in Water on the Corrosion of Aluminum and Steel; **C. F. Nixon**, head, Electrochemistry Department, before the Toronto, Ontario, branch, A.E.S., title: On Electroplating in the Automotive Industry; and **D. W. Hardesty** and **J. D. Thomas**, senior research engineers, before the Indianapolis, Indiana, section and Bridgeport, Connecticut, section, A.E.S., title: Accelerated Testing and Service Performance of Automotive Trim.

Quality Control and Reliability

Wilber Myers, director, quality control, Delco Appliance Division, before the Buffalo-Niagara Falls section, American Society for Quality Control, Buffalo, title: Machine and Process Capabilities.

Walter G. Maher, director of reliability, Rochester Products Division, before the Rochester, New York, chapter, American Institute of Industrial Engineers, title: The Task Force Approach to Reliability in the Automotive Field.

Edward R. Clark, supervisor, quality control, Detroit Transmission Division, before Wayne State University engineering students, Detroit, title: Quality Control as Applied to Industry.

W. L. Shelley, senior experimental engineer, Allison Division, before the mid-Indiana section, Society for Non-Destructive Testing, Indianapolis, title: Isotopes Are Our Modern Inspectors.

Robert B. Allured, senior project engineer, GM Manufacturing Staff, before the Detroit chapter, A.S.M., title: Material Defects—How to Find Them by Non-Destructive Methods.

L. A. Eckert, reliability engineer, Delco Moraine Division, before the Dayton section, A.S.Q.C., title: Design Reliability Prediction for Low Failure Rate Mechanical Parts.

From AC Spark Plug Division: **Austin J. Bonis**, director, reliability research and education, before the engineering institute, University of Wisconsin, Madison, title: Reliability; **Milton L. Stratton**, chief inspector, before the Battle Creek-Kalamazoo section, A.S.Q.C., Galesburg, Michigan, title: Selection and Training of Inspection Personnel; and **Hal C. Yost**, director of reliability, before the engineering institute, University of Wisconsin, Madison, title: Reliability Specifications and Standards, and before the Rochester, New York, chapter, A.S.Q.C., title: Military Reliability.

Research

From Allison Division: **R. E. Henderson**, chief, applied physics, before the American Power Conference, Chicago, title: Nuclear Fuel Cell Research, and **D. L. Dresser**, section chief, applied physics, before the 29th annual meeting, Institute of AeroSpace Sciences, New York City, title: Elements of Solar Collector Design.

C. T. Linder, supervisor, research laboratory, Delco Appliance Division, before the Brighton High School Physics Club, Rochester, New York, title: Energy Conversion.

From GM Research Laboratories:

Arthur F. Underwood, manager, before the Tri-State College sections, S.A.E.-A.S.T.M.E., Coldwater, Michigan, title: Research and the Future; **Joseph B. Bidwell**, head, Engineering Mechanics Department, before the National Conference on Driving Simulation, Santa Monica, California, title: Vehicle Control Simulation; **Robert Herman**, head, Theoretical Physics Department, **D. C. Gazis**, senior research scientist, and **R. F. Wallis**, U.S. Naval Research Laboratory, before the American Physical Society, New York City, title: Surface Vibrational Waves in Crystal Lattices with Complex Interatomic Interactions; **F. E. Jamerson**, senior nuclear physicist, before the 21st Physical Electronics Conference, Cambridge, Massachusetts, title: Experiments with a Noble Gas Plasma Diode Thermionic Converter; **Robert S. Cataldo**, senior research engineer, before the engineering seminar, Princeton University, title: Automatic Guidance for Automobiles; **H. J. Bauer**, senior research psychologist, before the Engineering Society of Detroit, title: The Concept and Practice of Human Factors Engineering; **L. D. Dyer**, senior research physical chemist, before a symposium, University of Virginia, Charlottesville, title: Rolling Friction on Single Crystals of Copper in the Plastic Range; **R. F. Majkowski**, research physicist, and **B. W. Joseph**, senior physics technician, before the Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Pittsburgh, title: Some Applications of the Principles of Time Resolution to the Problems of Analytical Chemistry; and **G. G. Scott**, research associate, before the Kettering Foundation symposium on g factor determinations, Dayton, title: Present Status of Gyromagnetic Ratio Experiments.

GM Research Laboratories personnel who made presentations at the 4th Symposium on Temperature, Its Measurement and Control in Science and Industry, Columbus, Ohio, include: **R. F. Moffat**, senior research engineer, titles: The Gradient Approach to Thermocouple Circuitry, and Gas Temperature Measurements; **C. W. Vigor**, senior metallurgical engineer, and **J. R. Hornaday, Jr.**, metallurgical engineer, title: A Thermocouple for Measurement of Temperature Transients in Forging Dies; and **W. G. Trabold**, research engineer, title: An Industrial Thermocouple Calibration Facility.

Solution to the Previous Problem:

Develop a Process Plan to Control Tolerance Stack Conditions for a Machined Part

By ROBERT DINDA
and L. C. LANDER, JR.
General Motors Institute

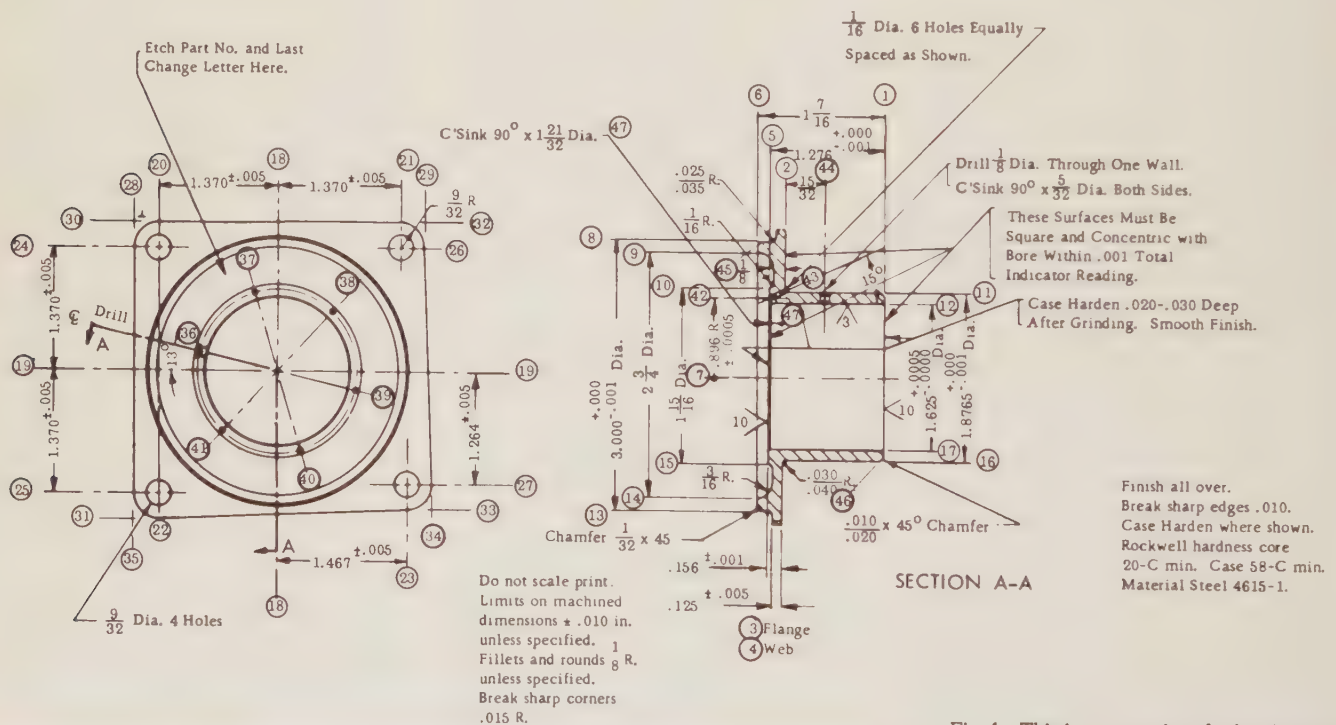
The development of a process plan leading to the effective control of tolerance stack conditions and the selection of tools and equipment requires consideration of all factors which have an effect on manufacturing operations. The development of a process plan for manufacturing the bearing cage requires, first of all, a determination of the founding dimensions. Next, general process capabilities must be considered and the operational requirements for each surface of the bearing cage determined. Finally, a comprehensive dimensional analysis is made for each processing operation to be performed to assure compliance with engineering specifications. The dimensional analysis is summarized in the form of a tolerance chart.

THE given data for the problem consisted solely of the part print (Fig. 1). This is usually the case with actual process planning problems of this type. As a first step in the solution to the

problem, each surface of the bearing cage is coded by number as shown in the part print. By using the surface codes, each dimension can be clearly identified by noting the code number of surfaces

between which the dimension is located. This system of defining each part print specification facilitates quick reference between the detailed process plan, which is to be developed, and the part print.

A preliminary analysis of the part print indicates that the bearing cage is to be sand cast. In the green sand molding process, a finish allowance of 3/32 in. is added to the finish dimension for each



Presented here is the solution to a typical process planning problem assigned to students enrolled in a manufacturing processing course at General Motors Institute. The approach used in solving the problem

is based on information obtained from manufacturing personnel associated with various GM Divisions. The problem requires a detailed analysis of the factors involved in process and machine selection.

Fig. 1—This is a part print of a bearing cage for which a process plan was to be developed. The encircled numbers denote code numbers of surfaces which facilitate easy identification of each dimension. For example, the 1-7/16-in. dimension defining the depth of the bearing cage is located between surfaces 1 and 6. Referring to the coded surfaces on the print, it can be seen that surface 1 is the hub face at the right end of the bearing cage and that surface 6 is the mounting face at the left, or flange end, of the cage.

PRELIMINARY DIMENSIONAL ANALYSIS

COMPONENT DIMENSIONS	PART TIME—FINISHED DIMENSION			FINISH MACHINING STOCK ALLOWANCE		SURFACE CODE	ROUGH CASTING DIMENSION	
	FRACTIONAL	DECIMAL						
	BASIC SIZE	BASIC SIZE	TOLERANCE	LEFT SIDE	RIGHT SIDE	FROM—TO	BASIC SIZE	TOLERANCE
1 7/16		1.43750	± .010	+	.09375	1—6	1.6250	± .03125
		1.276	+ .000 — .001	+	.09375	1—5	1.4635	± .03125
1 1/32		.46875	± .010	—	.09375	2—44	.3750	+ .03125
		.156	± .001	+	.09375	2—5	.3435	+ .03125
		.125	± .005	+	.09375	2—3	.3125	± .03125
1/8		.125	± .010	+	.09375	2—4	.3125	± .03125
		1.8765	+ .000 — .001	+	.09375	11—16	2.0640	± .03125
Cored Hole		1.6250	+ .0005 — .0000	—	.09375	12—17	1.4375	± .03125
		3.000	+ .000 — .001	+	.09375	8—13	3.1875	± .03125
		2.750	± .010	—	.09375	9—14	2.5625	± .03125
2 3/4 1 1/16		1.9375	± .010	±	.09375	10—15	2.1250	± .03125
		.896	± .005	0.0	0.0	7—42	(.8960	± .005)
		.3175	+ .011 — .012	+	.09375	2—6	.5050	± .03125
3/32		.2812	± .010	Solid	Solid	18—20	Not cored	Not cored
						19—24		
		.0625	± .010	Solid	Solid	19—(36-41)	Not cored	Not cored
(6)-1/16 1/8		.125	± .010	Solid	Solid	2—44	Not cored	Not cored
						11—12		
						28—29		
1.370+1.370+.28125+.28125		3.3025	± .030	+	.09375	35—34	3.4900	± .03125
1.370+1.467+.28125+.28125		3.3995	± .030	+	.09375	30—31	3.5870	+ .03125
1.370+1.370+.28125+.28125		3.3025	± .030	+	.09375	32—33	3.4900	± .03125
1.370+1.264+.28125+.28125		3.19655	± .030	+	.09375		3.38405	± .03125

Table I—A preliminary dimensional analysis of the bearing cage, such as that shown here, establishes the total stock which must be removed and aids in indicating the operations which will be required to remove the stock. All dimensions are expressed in decimal form to provide a degree of uniformity.

surface to be machined. For a casting of the size indicated for the bearing cage, casting dimensions can be held to within ± 1/32 in. A preliminary dimensional analysis of finished part dimensions is then made (Table I). This analysis, together with a consideration of the finish stock allowances, surface identifications, and corresponding rough casting dimensions gives some indication of the machining operations that will be needed because total stock removal requirements will be ascertained.

Cuts for Surfaces Analyzed

Once the basic operational requirements and process capabilities are known, the next step in planning the process is to analyze the number of cuts required for each machined surface.

Depending on the surface specifications, several different types of machining operations might be required for a single surface. For example, the specification for the inside diameter of the hub,

$$1.625 \pm 0.0005 \text{ in.} \\ - 0.0000 \\ 3 \text{ microinch finish,}$$

is typical of a surface finish requiring several types of machining operations each consisting of several cuts. Cast surfaces resulting from the green sand mold might be as smooth as 300 microinches whereas lapping, polishing, superfinishing, and in some cases honing operations, are used to obtain a 3 microinch finish. Precision machining must precede the final finishing operation to prepare the surface for honing or polishing. To minimize workpiece variation resulting from deflection of the tool and workpiece, progressively lighter cuts must be used to obtain the required degree of finish. Also, consideration must be given to the progressively higher degree of precision required of the machines used for each successive operation.

In contrast to the hub bore specification, the flange hub face at the left end of the workpiece has only a 1-7/16-in. dimension specified with an implied tolerance of ± 0.010 in. It is conceivable that a semi-finish machining operation would suffice for this surface coded number 6 (Fig. 1). The hub inside diameter and the left end flange face indicate the limits of the range of surface finishes and operations required to produce the bearing cage. From an analysis of machine capabilities, a listing can be made of the tolerances for the classes of cuts specified (Table II).

Using the specification for the main hub inside diameter and removal of the 3/32-in. stock allowance for machining as the ultimate objectives and guides, stock removal for each class of cut, in line with the tolerance capabilities, also can be realistically established (Table III). The operational requirements, in terms of the number and class of cuts, can be analyzed and summarized in chart form (Table IV). Since the finish machine cut and the finish grinding cut are not assigned, their stock allowance would be included in the semi-finish cuts. The total amount of stock removed from each surface, assuming a 3/32-in. machining allowance, should equal 0.09375 in. after the last machining operation is completed for a particular surface.

TOLERANCE FOR EACH CLASS OF CUT	
CLASS OF CUT	TOLERANCE
Turn, shape, mill, bore, drill	
Rough machining cut	± 0.010
Semi-finish machining cut	± 0.005
Finish machining cut	± 0.002
Grind	
Rough	± 0.001
Semi-finish	± 0.0005
Finish	± 0.0001
Hone, lap, polish	± 0.00001

Table II—This is a summary of the allowable tolerances to be used for each of the cuts specified.

STOCK REMOVAL FOR EACH CLASS OF CUT		
CLASS OF CUT	STOCK REMOVAL	TOLERANCE
Machine		
Rough	0.060	± 0.010
Semi-finish	0.021	± 0.005
Finish (not required)	(0.010)	$\pm (0.002)$
Grind		
Rough	0.008	± 0.001
Semi-finish	0.0042	± 0.0005
Finish	(0.0012)	$\pm (0.0001)$
Hone, lap, or polish	0.00055	± 0.00001

Table III—The amount of stock to remove for each class of cut, in line with tolerance capabilities, is summarized here.

The perimeter of the mounting flange has only one cut performed on it and, therefore, the entire 0.09375-in. allowance must be removed on the first and only machining operation. The deep cross section in the plane perpendicular to this surface should facilitate a 3/32-in. depth of cut with minimum deflection of the bearing cage. This single cut obviously requires a high quality machine capable of a relatively heavy cut while at the same time holding a rather close tolerance.

In the case of chamfering, several facing and turning cuts precede the chamfering operation, thereby minimizing the amount of stock removal. With only the slight amount of stock remaining to be removed and the relatively loose tolerance allowed, only one chamfering cut is assigned.

The right and left ends of the main hub have surface finishes of 10 micro-inches and, therefore, can be finished with a lapping operation. The main hub inside diameter can be finish machined with a honing operation to obtain the specified 3-microinch surface finish. These operations are consistent with information provided by a process capabilities chart* (Table V) showing the surface finishes available by common production methods.

Critical Location Surfaces Determined

Once the manufacturing operational requirements and finish stock allowances are determined, the next step is to select the critical surfaces on the bearing cage

	REQUIRED ON SURFACE																																															
CLASS OF CUT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46		
MACHINE																																																
ROUGH	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓																	✓	✓	✓		✓	✓	✓												
SEMI-FINISH	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓																																			
FINISH																																																
GRIND																																																
ROUGH	✓	✓			✓				✓			✓	✓																																			
SEMI-FINISH	✓				✓							✓																																				
FINISH																																																
HONE, LAP, OR POLISH					✓							✓																																				

Table IV—This chart summarizes the allocation of cuts required on various surfaces of the bearing cage.

for locating and measuring during the processing operations.

From an analysis of the finished part and rough workpiece dimensions, the back side of the mounting flange (surface code 2) would best accomplish location of the bearing cage with respect to a plane. The inside diameter of the main hub provides the most logical choice for fixing location with respect to a line and point. Location with respect to all three coordinate axes is fixed and consistent with the indicators of critical areas and qualifications of critical areas.

Both the back side of the mounting flange and the centerline of the main hub inside diameter are baselines of dimensions. Both of these finished surfaces have a close tolerance associated with them and are relatively large in area. They are, therefore, geometrically qualified as locating surfaces. Since they serve as baselines of dimensions, they are arithmetically qualified. Finally, the cross-section thickness and configuration of these surfaces makes them mechanically qualified as critical location areas.

The selection of the critical location areas determines the beginning of the operational sequence since, by definition, the critical area is the surface used for locating and measuring in subsequent operations. Therefore, they must be machined first if at all possible and practical.

The sequence of machining the remaining surfaces depends somewhat on the type of tooling to be used. While the bearing cage is located for turning the back side of the mounting flange and the inside diameter of the main hub, it would be advantageous to turn the outside

diameter of the hub and to face the rear end of the hub. This would facilitate control of the parallelism of the back side of the mounting flange and the end of the hub. In addition, concentricity of the inside and outside diameter of the hub could be easily accomplished by not changing the locational system. The economic savings to be gained by eliminating unnecessary removal and relocation of the workpiece from the holding device should not be overlooked at this point in the process plan.

Five Different Holding Devices Required

Through careful planning of the machining of the remaining surfaces and design of the holding device, the addi-

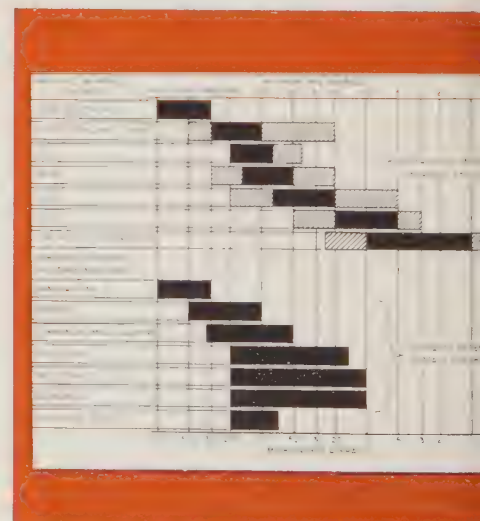


Table V—Shown here is a process capabilities chart reproduced from the 1954 edition of the Society of Automotive Engineers Handbook. Such a chart indicates the surface finishes available by common production methods.

*Society of Automotive Engineers Handbook, 1954 Edition, p. 206.

OPERATION LINE UP

OPERATION NUMBER	OPERATION DESCRIPTION	OPERATION NUMBER	OPERATION DESCRIPTION
10	Rough face main hub rear Rough turn main hub outside diameter Rough face flange rear Rough turn main hub inside diameter Locate on mounting flange front face and edge	150	Rough grind main hub face Locate on main hub front face
20	Rough face flange mounting hub Rough form web face Rough turn flange mounting hub Rough face flange front Locate on main hub inside diameter and flange rear	160	Rough grind flange rear Rough grind main hub outside diameter Locate on main hub inside diameter and front face
30	Normalize	170	Drill one $\frac{1}{32}$ diameter hole Ream one $\frac{1}{32}$ diameter hole Locate on main hub inside diameter, flange rear, flange edge Drill three $\frac{1}{32}$ diameter holes Locate on main hub inside diameter, flange rear, and reamed hole
40	Clean workpiece	180	Drill six $\frac{1}{16}$ diameter holes Locate on main hub, inside diameter, front face, and reamed hole
50	Semi-finish web face Semi-finish flange hub mounting face Semi-finish turn flange mounting hub Semi-finish hub face Semi-finish turn main hub inside diameter Semi-finish face flange front Chamfer flange mounting hub Locate on main hub outside diameter and flange rear	190	Drill one $\frac{1}{8}$ diameter hole Countersink $\frac{1}{8}$ diameter hole 90 X $\frac{1}{32}$ Locate on main hub inside diameter, front face, and reamed hole
60	Semi-finish main hub face Semi-finish face flange rear Locate on main hub front face and inside diameter	200	Harden and quench
70	Mask	210	Profile mill flange edges Locate on main hub inside diameter, front face, and reamed hole
80	Copper plate	220	Finish grind main hub front face Finish grind main hub inside diameter Locate on main hub outside diameter and flange rear
90	Unmask	230	Finish grind main hub rear face Locate on main hub front face
100	Remove excess copper	240	Finish grind main hub outside diameter Bump grind flange rear face Locate on main hub inside diameter and front face
110	Carburize	250	Finish grind mounting hub outside diameter Finish grind flange front face Locate on main hub inside diameter and flange rear
120	Clean	260	Micro-finish main hub inside diameter Locate on main hub outside diameter and flange rear
130	Deplate		
140	Rough grind flange hub face Rough grind main hub inside diameter Rough grind flange mounting hub Locate on main hub outside diameter and flange rear		

Table VI—This operation line up summarizes all of the processing steps required to produce the bearing cage.

tional operations necessary to complete the rough machining of the workpiece should be possible with just one locational system. Removal and relocation of the workpiece can be minimized by facing the main hub front (surface 5), the front side of the mounting flange (surface 3), the mounting hub face (surface 6), and the web (surface 4), as well as turning the flange mounting hub (surfaces 8 and 13) all in the same holding device.

The operations for rough machining can be repeated for semi-finish machining, rough grinding, finish grinding, and honing. This will facilitate the use of identical sets of holding devices throughout the process for all turning and face machining. The bearing cage, however, must be relocated for each group of cuts taken. For the operations discussed so far, 10 relocations of the workpiece are

required. In addition, three groups of drilling operations will require different jigs or fixtures—one fixture for holes perpendicular to the flange, one fixture for the six, 1/16-in. diameter holes, and one fixture for the 1/8-in. diameter hole in the hub. In all, five different holding devices will be required for 13 machining operations. Since two of the holding devices can be adapted to 10 different operations, these tooling requirements do not appear to be excessively high.

Part Should be Heat Treated After Semi-Finish Machining

Several operations, such as heat treating, are required to impart physical characteristics that cannot be incorporated in the raw stock or rough workpiece. The required final surface hardness of certain functional surfaces will result in excessive cutting tool costs (based on currently available tools) if incorporated prior to the final machining operations.

On the other hand, if the bearing cage is heat treated after all the machining operations are completed, the tendency of metal parts to warp could result in a functionally unacceptable part.

In planning the process for the bearing cage, sufficient stock must be left on the workpiece prior to heat treatment to permit re-machining to the required specifications. Since grinding is the most practical method for stock removal from hardened surfaces, the heat treating process should be incorporated into the process plan after the semi-finish machining, and just prior to rough or "green" grinding.

Along with the heat treating operation, carburizing in this case, certain preparatory action must be taken to insure that carburizing is restricted only to the bearing surfaces 1 and 5. The surfaces to be hardened should first be masked and the workpiece then copper plated. The masking is then removed to expose the

up in the bearing cage. These internal stresses necessitate a stress relieving operation, such as normalizing, with subsequent cleaning to remove any scale or foreign matter on the surface of the workpiece.

At this point in the process plan, a preliminary analysis of the manufacturing operational requirements can be summarized in an operation line up (Table VI). The next and final step is to develop a graphic presentation of the dimensional analysis in the form of a tolerance chart (Table VII). This is called the *Process Analysis and Plan*. Care

The completed Process Analysis and Plan is, in reality, a summary of all the previous analyses. It presents only that information which is of considerable value to such departments as inspection, work standards and methods engineering, tool and equipment procurement, and perhaps plant layout.

Define the Geometry of the Inner and Outer Tooth Contours of a Gear Type Oil Pump

By CARL M. SCHELL
Frigidaire Division

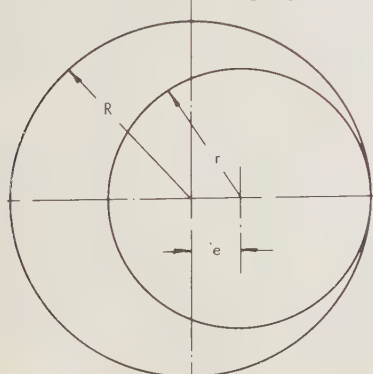
Assisted by Gerhard W. Sood
General Motors Institute

Fundamentals of analytic geometry often are applied by the engineer to problems in gear tooth design. The problem presented here deals with a gear tooth profile based on the hypocycloidal type of curve. Parametric equations are to be derived to prove that the lobes of an inner and outer rotor of a gear type rotary pump are in theoretical contact at all times.

AN application of the familiar gear type rotary pump is the oil pump for an automotive air conditioning compressor. This particular design incorporates inner and outer rotors which provide the pumping action (Fig. 1). The design of this rotary pump requires that the clearances between the inner and outer rotors be kept to very close limits to maintain volumetric efficiency and to provide for practically oiltight chambers formed between the teeth during rotation. This means that the surfaces of the rotor teeth, or lobes, must be in good theoretical contact at all times and in line contact at the various points throughout their periphery.

The contours of the rotor teeth can be considered to be approximately hypocycloidal (Fig. 2). A fundamental theorem of analytic geometry states that if a circle rolls on the inside of a fixed circle in the same plane, a fixed point on the circumference of the rolling, or generating, circle traces a curve called a hypocycloid. The hypocycloid for either the inner or outer rotor is produced by the trace of a given point on a generating circle as it rolls around the inside of the pitch circle.

Any mating pair of rotors must have a common generating circle and be related as shown in the following figure



where

R = radius of the pitch circle of the outer rotor

r = radius of the pitch circle of the inner rotor

e = distance between rotor centers.

Let

n = number of cusps of the hypocycloid of the inner rotor

$n + 1$ = number of cusps of the hypocycloid of the outer rotor.

Also, let R , r , and n be restricted such that

$$\frac{r}{R} = \frac{n}{n+1}.$$

In the preceding figure,

$$e = R - r.$$

Therefore,

$$R = (n+1)e$$

$$r = ne.$$

To substantiate that the contours of the rotor teeth are approximately hypocycloidal, assume that the pitch diameter of the inner rotor (Fig. 3) is a generating circle as it rolls around the inside of the pitch circle of the outer rotor. In fact, this is exactly the motion which occurs during actual operation of this type of rotary pump. As this generating circle rolls within the larger circle in a counter-clockwise direction, a given point P on the circle will trace a curve in a clockwise direction (line P_1-P , Fig. 3).

Problem

The problem is to derive parametric

Derive parametric equations to define a hypocycloidal curve



Fig. 1—Shown here are the inner and outer rotors used in a rotary type oil pump for an automotive air conditioning compressor. There is a difference of one lobe between the two rotors. The inner rotor is the driven member. The lobes form chambers which open and close during rotation and must be in tight contact with each other.

equations which will define the curve traced by the generating circle (Fig. 3) and which will also show that the lobes of the inner and outer rotors are in theoretical contact at all times.

For purposes of the problem, the inner rotor has seven lobes and the outer rotor has eight lobes. The parametric equations, however, are to be derived to provide a general solution where the number

Contributors to July-Aug.-Sept.

1961 Issue of

GENERAL MOTORS
ENGINEERING

JOURNAL

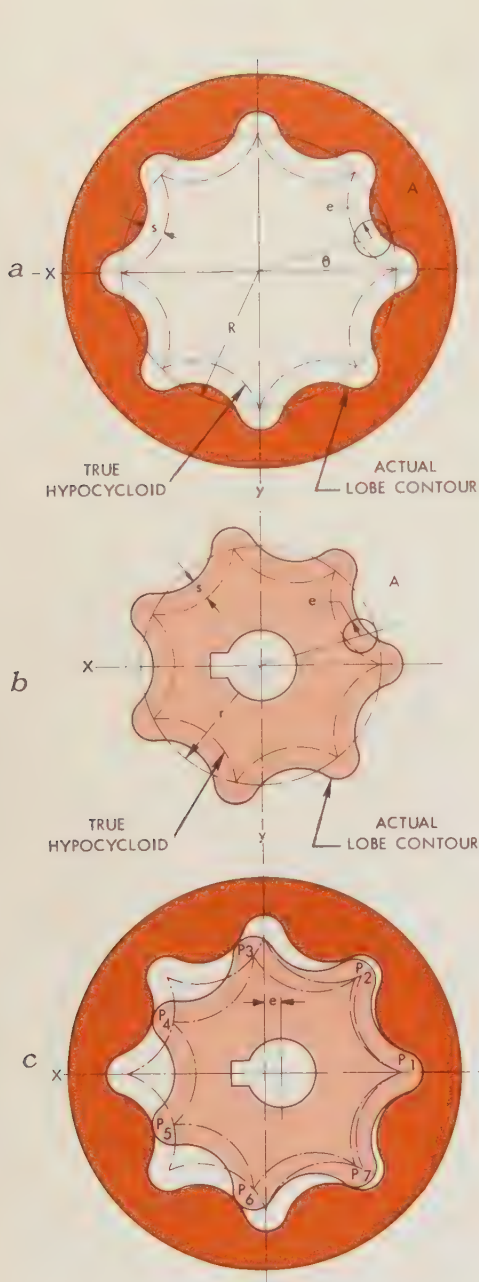


Fig. 2—The contours of the lobes for both the outer rotor (a) and the inner rotor (b) are approximately hypocycloidal. The mating pair of rotors have a common generating circle A of radius e . The pitch radius of the outer rotor is R and the pitch radius of the inner rotor is r . The dimension s is the normal distance between the true hypocycloid and the actual lobe contour. The angle between the geometric center of the rotor and the center of the generating circle is defined as θ . The cusps of the hypocycloid of the inner rotor lie on the hypocycloid of the outer rotor at points P_1 through P_7 (c). The inner rotor is the driven member and rotates on a shaft about its geometric center. The outer rotor also rotates about its geometric center, which is necessarily eccentric to the center of the inner rotor by a distance e . The outer rotor is nested in a cavity such that its outside diameter is its bearing surface.

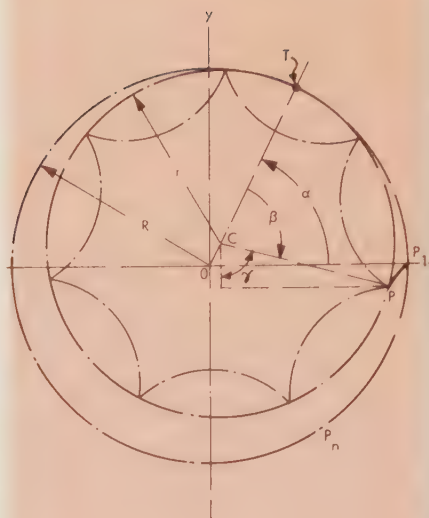


Fig. 3—The pitch diameter of the inner rotor, of radius r , is a generating circle as it rolls around the inside of the pitch circle of the outer rotor, which has a radius R . As this generating circle rolls around in a counterclockwise direction, a given point P on the circle traces a hypocycloidal curve in a counterclockwise direction, as indicated by the line P_1 - P . Parametric equations are to be derived which will define the hypocycloid which is generated for a rotor of n lobes, or teeth.

The center of the outer rotor is at point O and the center of the inner rotor is at point C . Angle α indicates the amount of counterclockwise rotation the circle of radius r has rolled on the pitch circle of radius R , starting from the point where P coincided with P_1 . In this amount of rotation the portion P_1 - P of the hypocycloid was generated. Point T indicates the point of tangency of the two circles after α degrees of rotation. The line O - T is a line through the centers of the two circles and their point of tangency. The line C - P connects the center of the generating circle of radius r with the point P which is generating the larger hypocycloid. The angle γ is merely an angle in the auxiliary right triangle whose hypotenuse is C - P . The point P_n indicates the point to which P will have progressed when the angle β first becomes 180° . The point P_n , therefore, locates the first cusp generated beyond P_1 .

of lobes n can be varied while maintaining the one lobe difference in any given pair of mating rotors.

Separate coordinate systems should be chosen for the rotors. Volumetric displacement of the pump and its physical dimensions should not be considered as part of the problem.

The solution to the problem will be presented in the October-November-December 1961 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

ROBERT
DINDA,




co-contributor of the problem, "Develop a Process Plan to Control Tolerance Stack Conditions for a Machined Part" and the solution appearing in this issue, is a faculty member of the Manufacturing Engineering

Department at General Motors Institute. He is responsible for undergraduate instruction, course development, and resident training program development and instruction.

Mr. Dinda joined General Motors in 1945 as a G.M.I. student in the co-operative engineering program. He was sponsored by Fisher Body Division. He received the B.I.E. degree from G.M.I. in 1950. Prior to joining the G.M.I. faculty in 1954, Mr. Dinda worked for Fisher Body as an engineering analyst and for the Cadillac Motor Car Division as a work standards engineer.

Mr. Dinda is a member of the American Society for Engineering Education, the Society of Automotive Engineers, the American Institute of Industrial Engineers, and Alpha Tau Iota, honorary society. He is currently doing graduate study for an advanced degree in industrial management at the Massachusetts Institute of Technology.




HUGH L. FISHER, contributor of "Some Rules for Determining Inventorship," and coordinator of this issue's "Notes About Inventions and Inventors," is a patent attorney in the General Motors Patent Section, Detroit Office.

His patent work has been in the mechanical, electrical, and electronic fields involving automatic transmissions, vehicle accessory drives, electrical controls both for machine tools and transmissions, reproducing apparatus, and test systems.

Mr. Fisher was graduated from the University of Cincinnati in 1949 with the B.S.M.E. degree. He then joined the Detroit Transmission Division in the college graduate trainee program and later became a project engineer. He attended the University of Detroit earning the LL.B. degree in 1953 after which he joined the Patent Section's Washington, D. C., Office. He was transferred to the Detroit Office two years later.


He is a registered professional engineer, a registered patent attorney, and a member of the Bars of Michigan, Court of Customs and Patent Appeals, and the U. S. Supreme Court. He serves in several committee activities of the American Bar Association, American Patent Law Association, and the Michigan Patent Law Association.



JAMES J. GUMBLETON, contributor of "Applying Radioisotope Techniques to Engine Wear Measurement," is a project engineer in the Power Development Group of the General Motors Engineering Staff.

Currently engaged in the design and development of automotive air conditioning systems, Mr. Gumbleton previously worked with the application of radioactive isotopes to engine research problems, principally in the area of engine wear. He joined General Motors Research Laboratories as a research engineer in 1954 and was transferred to the Engineering Staff in 1957.

Mr. Gumbleton received the B.S.M.E. degree from the University of Notre Dame in 1954, and the M.S.M.E. degree from Wayne State University in 1960. He is a member of Society of Automotive Engineers and the Michigan Nucleonic Society. He is the author of several papers including "Engine Voltage Requirements Using Spark Plugs Pre-ionized with Radioactive Gold," for which he received the S.A.E. 1959 Henry Ford Memorial Award.




WILLIAM H. JACKSON, contributor of "The Physiological Aspects of Automotive Heating, Ventilating, and Air Conditioning," is superintendent of the Product Engineering Department's laboratory and shop at Harrison Radiator

Division. He is responsible for the development of experimental samples, test apparatus, test tunnels, and automotive refrigeration compressors.

Mr. Jackson joined Harrison Radiator in 1941 as an inspector. After returning from military service, he attended General Motors Institute, receiving the B.M.E. degree in 1949. His promotions with Harrison Radiator have included project engineer, senior engineer, and supervising engineer—air conditioning. Some of his previous major projects include the design and development of automotive air conditioning systems and components.

Mr. Jackson is a member of the Society of Automotive Engineers and serves on the Society's air conditioning sub-committee. He has been a contributor to the S.A.E. *Journal* and the A.S.R.E. *Journal* and has had patents granted as a result of his work dealing with heat exchanger-muffler combinations for small engines.




L. C. LANDER, JR., co-contributor of the problem, "Develop a Process Plan to Control Tolerance Stack Conditions for a Machined Part," and the solution appearing in this issue, is director of specialized technical and part-time

training at General Motors Institute. As director, Mr. Lander is responsible for the administration of all specialized and part-time training programs conducted both in GM plants and at G.M.I. Such programs are developed at the request of GM Divisions to meet specific needs.

Mr. Lander, who received the M.E. degree in 1924 from the University of Cincinnati, joined General Motors in 1927 as a time study analyst with Frigidaire Division. A short time later he was transferred to G.M.I. as a member of the faculty. He has held various faculty positions including the chairmanship of the Production Engineering Department. He assumed his present position this year.

Mr. Lander is a member of the American Society for Engineering Education, the American Society of Mechanical Engineers, and the Engineering Society of Detroit. He is a former chairman of the Production Engineering Division of the A.S.M.E. and is a member of the general committee of this Society's Industrial Department. He has been a frequent contributor to the literature, having had papers published dealing with subjects in the area of methods engineering and principles of process planning.

KENNETH A. STONEX,



contributor of "How Roadside Ditches and Slopes Can Be Designed for Safety" is assistant director of the General Motors Proving Grounds, where he was originally employed in 1926.

He received the B.A. degree in mathematics from Michigan State University in 1933 and the M.A. degree in mathematics from University of Michigan in 1934. At Michigan State, he was elected to Phi Kappa Phi and Tau Sigma honorary societies. He returned to the Proving Ground at Milford, Michigan in 1934 joining the Technical Data Department. In 1942, he became head of the Mechanical Engineering Department when the Proving Ground was engaged in the testing of military equipment. He was named head of the Technical Data Department in 1945 and was appointed to his present position in 1956.

For years, he has been an active

participant on the Highway Research Board of the National Research Council. He has served on several committees dealing with various aspects of highway design, traffic control, and vehicle characteristics. This year he received the Highway Research Board Award for his paper, "Roadside Design for Safety."

Mr. Stonex also serves on committees of the S.A.E. and the Automobile Manufacturers Association. He has contributed several papers on the mathematical phases of automotive testing, testing facilities, and test track design.



DOUGLAS G. WILSON,

contributor of "Static Controls for Machines: Evolution and Design of the Transistor Circuits," is supervisor of the Industrial Electronics Group, Semiconductor Research and Engineering Department at Delco Radio Division. This Group is responsible for the development of industrial electronic products using semiconductors, with emphasis on control, sensing, and power conversion.

Mr. Wilson joined General Motors in 1955 as a senior project engineer in the Engineering Department of Detroit Transmission Division. He was transferred to Delco Radio in 1958 and promoted to his present position in 1959. He attended Wayne State University where he received the B.S.E.E. degree in 1949 and the M.S.E.E. degree in 1953.

His technical affiliations include membership in the American Institute of Electrical Engineers and the Kokomo, Indiana, Engineering Society. He also is a member of Sigma Xi, honorary society.

Prior to joining GM, he was employed by the Wayne Engineering Research Institute in Detroit.

HOWARD E. WRIGHT,

contributor of "Static Controls for Machines: Application to a Hypothetical Production Machine," is supervisor of the Equipment Development Section, Transistor Process Department, at Delco Radio.



Mr. Wright joined Delco Radio in 1955 as an engineer-in-training after receiving the B.S.E.E. degree from the University of Illinois. He was promoted to process engineer in 1956 and to senior process engineer in March 1960. Six months later he assumed his present position.

He is responsible for the development of equipment for manufacturing transis-

tors. His past projects included development of transistorized static controls for use in production machines in the manufacturing departments of Delco Radio and development work on other special production machines.

Mr. Wright is a member of the Kokomo, Indiana, Engineering Society and currently serves as chairman of the Society's higher education committee.

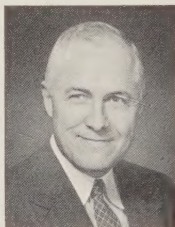
Information about the Authors of "Engineering and Education"



CHARLES S. DRAPER is professor and head of the Department of Aeronautics and Astronautics and director of the Instrumentation Laboratory at the Massachusetts Institute of Technology. His contributions have brought him world-wide recognition for his pioneering research and development efforts in the field of inertial navigation for manned aircraft, missiles, and naval vessels. He is a member of several advisory groups of the military services.

In the teaching field, he is responsible for an extended curriculum of courses in instrument engineering and fire control which lead to degrees for Navy and Air Force officers.

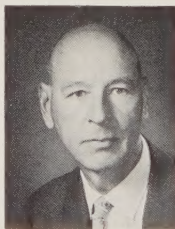
Dr. Draper graduated from Stanford University in 1922 with a B.A. degree in psychology. He then entered M.I.T. and has been associated with the Institute ever since. He has three degrees from M.I.T.—B.S. in electrochemical engineering (1926), S.M. without specification of department (1928), and Sc.D. in physics (1938). He is a member of several engineering, scientific, and honorary societies and has received numerous awards from professional, civic, and governmental organizations.



THOMAS K. SHERWOOD is professor of chemical engineering at the Massachusetts Institute of Technology. Following graduation from McGill University in 1923 with the B.Sc. degree, he entered M.I.T. where he earned the degrees of S.M. in 1924 and Sc.D. in 1929. Except for a two-year period on the faculty of Worcester Polytechnic Institute, he has been at M.I.T. since 1924. He was named professor in 1941 and served as dean of engineering from 1946 to 1952.

A member of many engineering, scientific, and honorary societies, and the recipient of two honorary degrees, he has authored over sixty papers on chemical engineering subjects such as drying, heat transfer, absorption, extraction and eddy diffusion. His awards include the William H. Walker Award (A.I.Ch.E.) and the U.S. Medal for Merit. He was named Priestly lecturer in 1959.

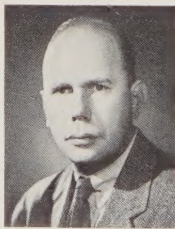
Dr. Sherwood was a consultant to the War Department and other agencies during World War II. Presently, he is a consultant to the U.S. Department of Interior Saline Water Program.



JOSEPH H. KEENAN has been head of the Department of Mechanical Engineering at Massachusetts Institute of Technology for the past three years and is now relinquishing that post to return to teaching and research. A noted authority on thermodynamics, his interests also include jet and rocket propulsion and gas turbines.

He is the author of *Thermodynamics* and a co-author of *Thermodynamic Properties of Steam*, *Thermodynamic Properties of Air*, and *Gas Tables*. He has represented the United States at several international meetings on the properties of steam. He is a member of several honorary and professional societies and has made notable contributions to the activities of the American Society of Mechanical Engineers.

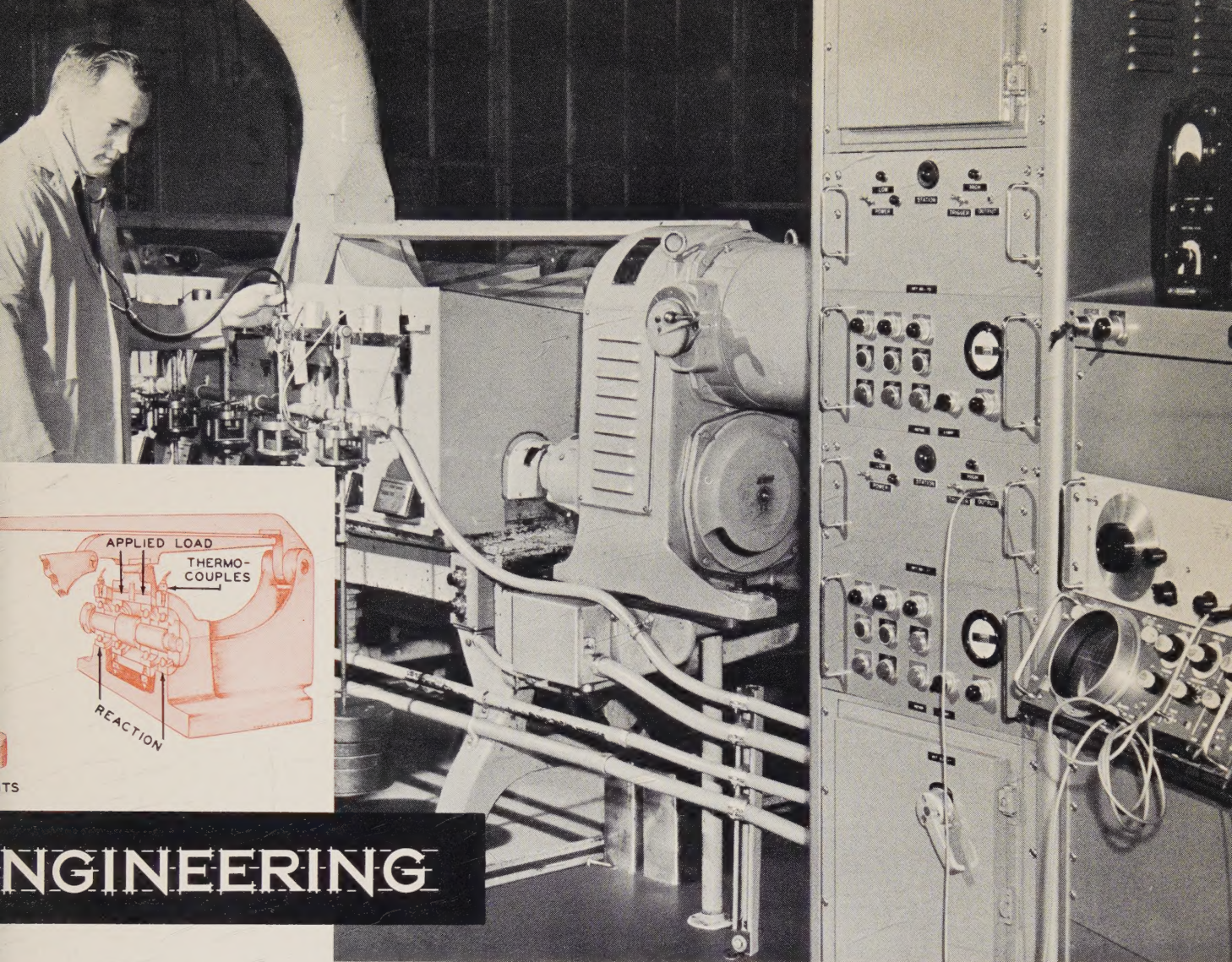
Professor Keenan graduated from M.I.T. in 1922 with the degree of B.S. in naval architecture and marine engineering. In 1928, after working in industry on steam turbine design, he became assistant professor at Stevens Institute of Technology. He joined the M.I.T. Staff in 1934 becoming a full professor in 1939.



JOHN B. WILBUR, head of the Department of Civil and Sanitary Engineering from 1944 to 1960, is now a consulting professor of engineering at the Massachusetts Institute of Technology. Widely known as a structural engineer, he has had extensive experience, including consulting work, in the fields of bridge design and highway construction.

M.I.T. granted Dr. Wilbur the B.Sc. degree in 1926, the S.M. degree in 1928 and the Sc.D. degree in 1933. He worked in the railroad industry for two years and in 1930 he rejoined the M.I.T. faculty. Among his contributions at the Institute were the development of the Structural Analysis Laboratory and the development and building of the simultaneous calculator, a computer that solves nine linear simultaneous equations.

During World War II he was a consultant to various governmental agencies and is presently a consultant to the Armed Forces Special Weapons Committee. A member of many engineering and honorary societies, he also has written numerous technical papers and co-authored two textbooks on structural analysis.



ENGINEERING

ASSIGNMENT IN GM

The ball bearing is a seemingly simple mechanism. But it can present some complex problems in design and application particularly when the operating requirements are unusually severe. Examples of such problems are found in many of today's applications, especially in the fields of aircraft, rockets, and nuclear power equipment.

Engineers at New Departure Division continually seek solutions to bearing problems by evaluating the use of different materials, new designs, and other improvements. An aid to this developmental work is the Physical Test Laboratory at New Departure. Here, testing programs are conducted to help analyze a variety of bearing operating characteristics such as endurance, lubrication, and resistance to heat or corrosion.

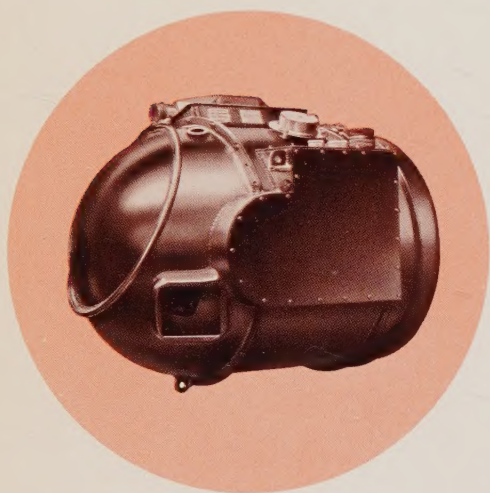
Besides conducting tests, engineers in this laboratory have the opportunity to use their mechanical and electronic backgrounds in creating special test machinery and putting it into operation. For example, Ronald Nodine is a junior engineer whose duties include ball bearing fatigue analysis, bearing seal development testing, and grease lubricant evaluation. In connection with his work, he is shown checking an automatic shut down system for the bearing endurance test machines illustrated above.

The ball bearing endurance test machine (left) is composed

of banks of units of the type illustrated in the inset drawing. Although the view shows only the application of radial load, thrust loads can be applied to the center bearings by means of a calibrated set of Belleville springs (not shown). The thermocouples are used to measure bearing temperatures under various operating conditions.

The automatic shutdown system operates on the principle of measuring the vibration level at a bearing station and stopping the test machine if the vibration reaches a value denoting failure of a bearing. This development means that testing time can be increased by as much as 40 per cent because the machines can operate over a week-end without an attendant. Previously, a stethoscope was used to make an audible detection of bearing failure. Mr. Nodine is shown checking the new method against the old while he is in the process of setting the vibration level for automatic shutdown of the machine.

Mr. Nodine, after graduating from high school, spent two years in the Army Ordnance Corps. Following discharge, he entered the University of Connecticut and graduated with a B.S.M.E. degree in June of 1959. He then joined New Departure and participated in a one-year training program covering all phases of the Division's operation. Mr. Nodine was assigned to his present position in the Physical Test Laboratory in 1960.



GENERAL MOTORS ENGINEERING JOURNAL

